DÆDALUS

CREATIVITY AND LEARNING

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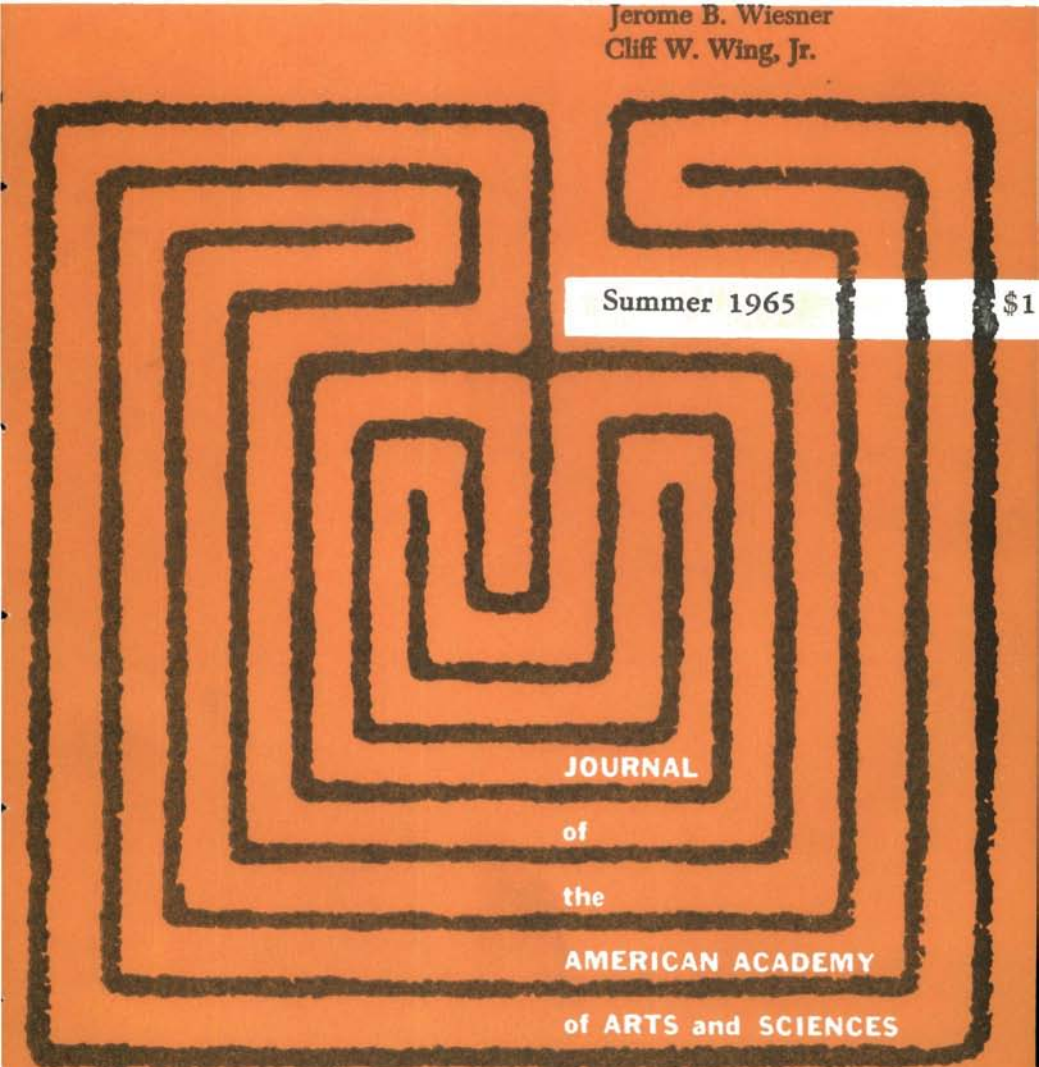

Summer 1965 $1

JOURNAL
of
the
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EDITORIAL OFFICE: *Dædalus,* the Journal of the American Academy of Arts and Sciences, 7 Linden Street, Harvard University, Cambridge, Massachusetts 02138. All communications to the Editor should be sent to that address.

SUBSCRIPTION OFFICE: American Academy of Arts and Sciences, 280 Newton Street, Brookline Station, Boston, Massachusetts 02146.

SUBSCRIPTIONS: *Dædalus* is published quarterly. Subscription rate in the United States, $5.50 a year; foreign $6.00; single copies (regular current issues), $1.50 domestic, $1.75 foreign; for a back issue add $0.50. Double issue: $3.00 domestic, $3.50 foreign; for a back issue add $0.75. Subscription orders should be sent to the Subscription Office.

Published by the American Academy of Arts and Sciences

Printed in the United States of America. Printing Office: 2901 Byrdhill Road, Richmond, Virginia

Library of Congress Catalog Card Number: 12-30299

Second-class postage paid at Richmond, Virginia

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Preface to the Issue "Creativity and Learning"

CREATIVITY IS a subject whose boundaries are largely uncharted. Whether one agrees with Philip H. Abelson that it is "a comparatively elusive target," and that "an understanding of the circumstances producing optimal creativity is still at a primitive stage," or whether one holds with E. Paul Torrance that if it is to "be viewed scientifically, creativity must be defined in a way that permits objective observation and measurement," the scope of inquiry in this vast area remains uncertain. Even when attention is focused largely on scientific and scholarly creativity, as it is in this issue of *Dædalus*, there is a clear necessity to explore themes whose relevance may not always be immediately apparent.

The setting which affords hospitality for creative endeavor is of great consequence. This, however, implies more than suitable institutional organization or adequate financial support, for the creation of a proper climate presupposes the existence of men and women whose education has fitted them for a particular sort of intellectual effort. Both Jerome Wiesner and J. Douglas Brown are concerned with exploring various dimensions of this problem. Because each emphasizes the critical importance of a certain kind of early education, it is useful to be reminded by David Hawkins of the failure of many schools to instruct in such a way that the meaning of the "extraordinary technological and material evolution of the last century or two" becomes the property of more than a minority in our society. Jerome Kagan, in a quite different spirit, raises questions about how the young (and old) do, in fact, learn, and why particular methods of learning will serve some and not others. The unconscious psychic component in learning and thinking is the explicit concern of Lawrence S. Kubie, who insists that we still know too little about these matters and that only the development of substantial new research can provide us with the kinds of data that we need. Loren Eiseley's essay on Darwin and Coleridge may be

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read as a "case study" of rival opinions on conscious and unconscious creation in two undeniably creative minds.

Philip H. Abelson examines scientific creativity in a context which emphasizes the significance of what he calls "group stimulus." He does not argue that this is a necessary condition of creativity, but offers evidence to suggest where it has recently been important. J. Douglas Brown is interested in describing the circumstances which facilitate the development of creative teacher-scholars. He is not persuaded that more efficient organization and new methods can by themselves satisfy the urgent need for such people. Cliff W. Wing, Jr., and Nevitt Sanford direct their attention to the American college. Mr. Wing's concern is to describe procedures which would contribute to "identifying genuinely creative talent"; once students are admitted to college, an even more difficult task remains—to frame a curriculum which encourages creative effort. Mr. Sanford sees this as a problem not only for the students but also for those who undertake to teach them. He provides, with appropriate detail, a model calculated not to replace existing "specialized inquiry," but to remove it "from its position of dominance over all higher education." E. Paul Torrance describes tests which he and his colleagues have developed to measure creativity. Their findings, the author suggests, indicate directions which others would do well to consider in thinking about educational reform.

Readers of *Dædalus* will find a new section, entitled *Documents*, at the back of this issue. Under this rubric, we intend, from time to time, to publish reports which we think particularly significant, and which many of our readers will not have seen. We inaugurate the department with two such documents. The first, Caryl P. Haskins' Report as President to the Carnegie Institution, surveys the dynamics of contemporary scientific endeavor. The second, George B. Kistiakowsky's paper "On Federal Support of Basic Research," appeared originally as part of a study undertaken by the National Academy of Sciences in response to an invitation from the Committee on Science and Astronautics of the United States House of Representatives.

Earlier versions of several essays in this issue of *Dædalus* were originally presented at a Conference on Education for Creativity in the Sciences at New York University. We are grateful to Professor Sidney G. Roth for bringing them to the attention of the Editors.

S.R.G.

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JEROME B. WIESNER

Education for Creativity in the Sciences

THE RAPID expansion of scientific and technical fields, and the spiraling rate of change within them, has created many puzzling, vexsome problems for the society at large and the technical community in particular. The profusion of fresh concepts and theories, new materials and novel devices has resulted in rapidly changing products and production techniques and larger technical systems characterized by greater and greater complexity.

An obvious consequence of these trends is the accelerated technical obsolescence of the material basis of our society leading to rapid replacement of machines in industry and appliances in the home. Another consequence is the obsolescence of much of the specialized training of the manpower that sustains the system. For example, although it was possible to train an engineer twenty-five years ago on the assumption that his skills would be useful for most, if not all, of his professional life, such an approach to engineering education is altogether unrealistic today. Ten years is perhaps the longest time a typical research or design engineer can expect to be effective today without a continuing education or a major effort to refurbish and update both his basic and his specialized professional skills. So it is not surprising that the demand in some of the main technical fields for the most recent graduates of the better engineering schools exceeds the demand for experienced men with, unavoidably, more dated academic training.

The emphasis on technical innovation has drawn attention to the fact that a very small number of the working scientists and engineers are responsible for most of the new ideas. Workers with developed creative gifts are in very short supply and great demand.

These facts suggest not only the need to review what is now being taught, with the aim of enhancing the creative ability of

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students and of developing skills which might remain productive longer, but also the importance of considering what the educational system can contribute to the periodic academic updating of the specialists it has already produced. We should explore what techniques can best be applied to educating for creative productivity in science and engineering.

Perhaps it is best to begin by describing how I am defining the terms "productivity" and "creativity." Although these words are frequently used synonymously, it is possible to recognize a useful distinction between them. The term "creativity" is principally used to mean activity resulting in contributions that have novelty and value in the intellectual sphere of human experience, including the sciences, as well as literature, music, and the visual arts. In all such contexts, "creativity" universally implies a departure from, and advance beyond, what is conventionally attainable. However, there is an important characteristic of creative contributions in science that is not significantly present in creative contributions in many other fields, namely, quantitatively definable logical relationships to preexisting scientific knowledge. Thus, although the emotional and intuitive appeal of a new idea or concept, or its esthetic richness, may make it "creative" in a philosophic or artistic sense, normally it must also meet the criterion of being logically relatable, in quantitative terms, to the body of science in order to be considered scientifically "productive." An idea must clearly follow from what is already known if it is to result in an enrichment of available scientific knowledge or of associated technologies.

This distinction is of more than purely semantic interest because of our concern with both "education" and "creativity/productivity." Clearly an element of rigorous, logical discipline must be characteristic, at some point, of the creative efforts of a productive scientific worker, and such discipline may be altogether absent from behavior generally called "creative" in non-scientific fields. Accordingly, by the phrase "productivity in the sciences" I mean to encompass the sum of intellectual activities which contribute to the expansion of scientific and technological knowledge. Thus, "creativity" is a more general term than "productivity," and when "creativity" or "creative" is used in connection with science and technology, it is to be assumed that productivity is also involved.

Now, what kinds of creative activity does society expect from scientists and engineers? For our purpose it is sufficient to group these activities into the following three categories: (1) *scientific*

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research, concerned specifically with the problem of increasing our understanding of nature; (2) *applied scientific and technological research*, concerned with the development of new tools, techniques, and tool-technique combinations for the solution of particular problems involving practical (rather than purely philosophical) objectives; (3) *engineering design*, primarily concerned with esthetic, materially efficient, and/or economic adaptation of available technology to particular social purposes. The common creative element in these activities might be described as that imaginative insight which, by effectively increasing what is already known, makes available to mankind a somewhat different, broader, and better understood body of experience.

However, if a direct connection between an individual's capacity to undertake creative activity and the educational process to which he has been subjected is to be usefully established, we should fix our attention on scientific research, because the characteristics of such research, and its successful practitioners, have been perhaps more carefully studied than those of other creative activities.

Research creativity is best delineated by a review of the characteristics of eminently successful, that is, extraordinarily creative, scientists. Most of them (as indicated in the pioneering studies of Anne Roe) have the following factors in common: a childhood environment in which knowledge and intellectual effort were so highly valued for themselves that an addiction to reading and study was firmly established at an early age; an unusual degree of independence which, among other things, led them to discover early that they could satisfy their curiosity by personal efforts; an early dependence on personal resources, and on the necessity to think for oneself; an intense drive that generated concentrated, persistent, time-ignoring efforts in their studies and work; a secondary-school training that tended to emphasize science rather than the humanities; and high, but not necessarily remarkably high, intelligence.

In addition to these more or less personal attributes of creative scientific workers, there are some plausible and reasonably well accepted psychological descriptions of the creative aspects of the research process itself.*

Successful conduct of research is associated more with particular mental attitudes and habits than with specialized techniques or procedures, although the latter may be present in certain phases of the

* My version of these descriptions and some of my conclusions have been most influenced by the works of Roe, MacKinnon, and Mooney.

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work. Certainly, creative persons develop styles of their own which are characteristic of their mode of working. Such attitudes and habits permit relatively unrestrained observation of phenomena and a persistent, uninhibited pursuit of logical consequences in spite of recurring need to revise or reject prior convictions.

The specifically creative phases of the research process appear to be relatively loose, informal, and personal, and have very little in common with the highly structured, logical, and formal public descriptions of the results. It seems clear that it is this private, relatively unstructured, and perhaps only partly conscious process that results in the creation of new ideas and insights.

Thus, although analogy and metaphor are techniques definitely proscribed for formal reasoning, they may turn out to be dominant in the intuitive, sometimes illogical and initially random process of scanning and searching for new connections and clues. To be creatively efficient such scanning and searching might well need an uninhibited, habitually exercised capability to consider, and explore, ideas in direct contradiction to accepted facts; and, obviously, the larger the universe of relevant data, the greater the efficiency of the process.

Now let us assume that this description of the creative process and that of the characteristics of outstandingly creative scientists are both valid. From the point of view of our general interest in increasing productivity in the sciences, the important question then becomes: What kind of educational methodology would tend to maximize both the number of individuals who are scientifically productive and their personal scientific productivity? Since the descriptions we have provided above do not, by any means, have the status of scientific facts, inferring an appropriate educational process from them is clearly a highly speculative undertaking. However, a more solid scientific basis for discussion of this subject does not appear to be available now. Accordingly, we shall go ahead, keeping in mind, however, that the scientific texture of our conclusions is likely to be rather soft.

The essential problem is that of devising an educational process which will allow the development of easy competence in rigorous methods of reasoning; the amassing of the large collections of facts and theories that constitute current knowledge; and the inculcation of habits for efficient use of available ideas and facts, without the simultaneous establishment of inhibitions and intellectual rigidities that limit the free and imaginative use in research (or in

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other work) of all the skill and knowledge that have been acquired.

Fifty years ago Alfred North Whitehead remarked that "the key fact in education, and the reason for most of its difficulties" is that "necessary technical excellence can be acquired only by training which is apt to damage those energies of mind which should direct the technical skills." The student with an enormous fund of knowledge, polished techniques, and a total lack of creative ability is an all-too-frequent product of our system. We can take a somewhat more positive approach to the problem: we seek not only to provide training without damaging youthful drive and imagination, but to go beyond that and teach the youthful mind how it might use all of its resources for creative intellectual pursuits in a more effective manner. The only time-tested formula for carrying out this process is that of associating the prospective scientist with a person who has demonstrated both this creative ability and the capacity to transfer his spirit to youngsters.

Focusing attention, for the moment, on the needs of individuals rather than society as a whole, we can specify the main characteristics of an educational process designed to enhance productivity in the sciences.

The basic habit of maintaining a skeptical, actively critical point of view toward all knowledge and opinion must be ingrained. Such habits will minimize the development of unconscious inhibitions against consideration of the widest possible spectrum of possibilities in approaching a problem of interest.

There must be encouragement and stimulation of imaginative and unconventional interpretations of experience in general; this is particularly true in problem-solving activities. It is important, especially in childhood and early youth, that novel ideas and unconventional patterns of action should be more widely tolerated, not critized too soon and too often.

Since logically interrelated bodies of factual material can be more efficiently scanned and searched, the accumulation of facts during training should emphasize principles, laws, and structural relationships.

We must explicitly encourage the development of habits and skills in looking for, and using, analogies, similes, and metaphors to juxtapose, readily, facts and ideas that might not at first appear to be interrelated. Early in this development we should foster a clear understanding of the special character and usefulness of the private, informal process of conducting a search for new ideas and insights;

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and of the distinction between it and the equally necessary but more elaborate and rigorous machinery needed for verification of results, and their systematic development for incorporation into the accepted body of knowledge.

We should help the maturing individual develop a personal "style," suited to his personality, abilities, and complement of knowledge, for approaching problems, research or other, in his special fields of interest. This "style" should reflect the particular mix of mental work habits he has developed to define a problem and to go from it to a spectrum of possible solutions. In a more fundamental sense it would also reflect the habitual pattern of resolving the apparent contradiction between the individual's private, imaginative, playful approach to research and the more formal and rigid reasoning process he would employ to establish and extend the results of that research so that it became "productive" as well as "creative."

Although the above "prescription" has been formulated for the educational needs of future research scientists, all that has been said is equally applicable to engineers whose careers will be devoted to enlarging the boundaries of applied science and technology. As Gordon S. Brown, Dean of the School of Engineering at M.I.T., has pointed out, such engineers "are composers rather than arrangers. Their work is predominantly intellectual, and it depends on a profound knowledge of science. They may work as scientists, but their knack of seeing the useful rather than searching for the unknown characterizes them as engineers."

Whether we refer to the research scientist or the research engineer, it is obvious that he will be professionally productive only if his knowledge of relevant subject matter extends to the frontiers of his own fields of activity. In general, this means that his studies must be pursued through the doctoral level. And, just as the purpose of the curriculum followed by the future scientist will be to saturate him with an essentially instinctive understanding and appreciation of the fundamental scientific disciplines, so must this be the case with the research engineer. He must be able to think quantitatively and to formulate his problem in terms of conceptual or mathematical models as a matter of second nature. No other set of skills can insure to the same degree that his work will be productive, and that his training will not rapidly become obsolete.

Let us assume that the above set of specific proposals defines reasonably well the requirements of an effective educational program for productivity in science. What then?

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If we were dealing with a technical problem involving the application of the physical sciences, having agreed on a series of reasonable approaches to solution, we could proceed to our laboratories and at once make a start on our newly defined research program. The same sort of rapid response is equally applicable to defining research problems that could be readily undertaken by psychologists or experimental educational institutions. However, our immediate need is not only for further research but for active programs, in the form of large-scale educational experiments, to implement what we already know. But to proceed along such lines we shall have to be concerned as much with stimulating necessary social action as with specific technical matters.

We do not now have useful techniques for predicting with comfortable reliability which individuals will turn out to be creative in the sciences or in any other field, no matter how great an investment we make in their education. Nor does it appear likely that such techniques will be developed in the immediate future; in any case, it would not seem prudent to plan national action on the assumption that they will soon be available. This means that if we are to optimize the general social use of our human resources, there is no alternative to giving as many students as can meet the minimum intelligence requirements the knowledge necessary to provide a reasonable opportunity to be productive in the sciences. However, although this level of intelligence is fairly high (estimated by some to be an IQ level of about 130) there are very large numbers of men and women, at and above this level, who do not now reach the university. This is particularly true among members of the underprivileged groups, especially Negroes. Obviously, our society is incurring a major loss in scientific productivity because of this circumstance, and ways must be found to overcome such needless national waste. As a matter of fact, it is possible to construct a very persuasive argument that our long-term national capabilities in science and technology can be more surely, and perhaps more quickly, enhanced on a large scale by providing motivation and educational opportunities for minority groups than by any other means now open to us. It would be desirable, too, for more women to seek careers in science.

Strong individual motivations for intensive intellectual training extending over many years are necessary to prepare a person for productive work at the frontiers of science and technology. Unless society's scale of values is modified to provide more generally

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enthusiastic approval of intellectual pursuits—including scientific creativity—we cannot expect any large proportion of those with the necessary natural endowments to begin, and to continue with persistent devotion, the rewarding but difficult labors involved. The attainment of intellectual excellence must become, when compared to other personal ambitions and accomplishments, much more generally accepted by our youth as a challenge rather than as an evidence of "squareness." But even strong motivations are not enough. Personal interest in, and devotion to, the sciences and mathematics through the early years of schooling cannot mature without appropriate learning opportunities, nor can a broad mastery of the subject matter be conveyed in the absence of imaginative and stimulating teaching. I am not suggesting any great increase in schoolwork at an early age, at least not in the better schools. Rather, I am proposing that the subject matter be real science, appropriately presented. It is as easy to present many important and basic ideas as it is to present the confusing hodgepodge often passed off as science in the lower grades. Although elementary courses will make no claim to great thoroughness, they should at least start in the right direction and include opportunities for discovery and experimentation to stimulate the curiosity and develop intellectual self-reliance. In addition to its direct contribution to superior intellectual development for future creativeness, properly planned early training might well provide a more reliable basis for selection of the unusually well endowed. It would also result in the better use of the student's time and energy, and of university resources when he reaches that level of work.

The first step toward a more effective education is to raise the level of effort in mathematics and the sciences to the level of the students' capabilities. We now believe that children can undertake serious learning at a much earlier age than we had thought previously. Experience has shown that meaningful science and mathematics can be taught in the earliest grades. Not only should science courses be started earlier but they should be part of the curriculum in each year for those who show interest and special aptitude.

Many people are impressed by the fact that the Soviet Union's ten-year cycle of primary and secondary education requires that *all* students must take five years of physics, six years of mathematics, three years of biology, and four years of chemistry, with the course content of the work during the last two years being comparable to that of the usual introductory courses in these subjects offered in

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our liberal arts colleges. By contrast, our corresponding school period contains twelve rather than ten years but provides on the average only one-fifth as much training in mathematics and the sciences. There is insufficient evidence to show that the intensity of early Soviet scientific training is either necessary or desirable, particularly if it involves sacrifices of some emphasis on the humanities, but it is evident that the standard program in our schools is far from optimum.

Earlier I listed the characteristics which an educational program should have if it is to develop the latent creative ability of the youngsters. The traditional high school and university science programs are very poor when judged by these criteria. Their primary accomplishment is to transfer information rather than to convey the spirit or method of science. And even much of the substance is inadequate. The typical text for physics, biology, or chemistry fails to reflect much of the understanding achieved in these fields during the past two decades. In fact many elementary texts confuse science with technology; witness the many photographs of steam engines, rockets, jet aircraft, and nuclear explosions that fill their pages. Courses for the early grades, generally limited to observation and classification of nature's objects, plants, animals, and minerals, fail to convey any feeling for the imaginative, creative character of scientific work and too often establish a dislike which can never be overcome.

We know what needs to be done. Experiments in curriculum development, in teacher-training institutes, in the enrichment of the intellectual environment for students whose homes are lacking in appropriate opportunity, in how people learn, and so forth, have charted the path for a major upgrading of elementary and secondary schools. But to reach the goals we need to apply these ideas in a determined manner. We must produce the new curricular materials; we must have more teachers, particularly teachers with a current education; we must do more research and development in the field of learning; and we must vastly improve the physical facilities of our educational system.

Fortunately an excellent beginning has already been made in curriculum development programs and teacher-training institutes sponsored by the National Science Foundation, covering biology, physics, chemistry, and mathematics. The curriculum development work so far includes only high-school courses. (Furthermore, the teacher-training institutes cannot take care of all of the teachers

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who would profit by participating.) Other subjects and additional grades need to be included.

Rapid progress in this sector will obviously be difficult to realize because of the present large number of students, the relative lack of involvement by the Federal Government at this educational level, and the highly fragmented character of public responsibilities for our educational system.

There are a number of outstanding high schools, such as the Bronx Science High School, that place heavy emphasis on education in the sciences. Possibly more communities, or at least individual states, should establish a science high school. Such schools could be operated under the direct control of the appropriate state universities with financial support provided, at least in part, by the Federal Government. The admission of students would be on the basis of rigorously competitive academic aptitude examinations, with the costs of attendance for those winning admission but in need of financial assistance being provided by the school through arrangements with the state and the Federal Government. Such schools could become models of educational excellence and centers for experimentation with new methods of teaching and new curricula, quickly and vigorously stimulating the advance of science and of general education throughout the country.

The need for educational reform exists at the university level, too. The shortcomings in content and method found in the elementary- and secondary-school science programs also are prevalent here, and the same opportunities exist for major improvements in teaching. I believe that the present emphasis on formal learning in the colleges and universities and the almost complete lack of contact with real research in the undergraduate years can be very harmful. The student who has had no opportunity to experiment and explore by himself before going to college often ends up bound to rigorous logical methods, afraid to experiment or indulge in flights of fancy, and quite unproductive as a working scientist or engineer. Incorporating new knowledge, eliminating the obsolete, preparing effective laboratory activities, employing teaching aids, including movies and computers, and integrating it all, are concrete steps toward improvement of college-level teaching. Groups at Cal Tech, Berkeley, Illinois, and M.I.T. are working on new college courses in the sciences, but this effort, like those at the lower grades, is just a start in a field where the opportunities (and deficiencies) are almost endless.

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There is obvious need for imagination and creativity in educational innovation at the college level, but if real progress is to be achieved, a major effort must be made to attract many of our best minds to the work. The science course development programs have done this to a remarkable degree already, but there is still room for many more helpers. Incidentally, as we proceed along these lines and outstanding scientists and creative individuals from other fields join in the effort at all levels, the profession acquires a new dignity and with it a new interest for our more able youngsters. Only if this trend can be accelerated and the growing effort sustained for many years can the teaching profession succeed in meeting the educational needs of our society.

It is becoming quite clear that more rapid national progress along such lines must be evident soon if our most vital national resource, the talent of our youth, is to be provided adequate opportunity to be intellectually, and more generally, productive in tomorrow's world. That world will be more complex than it is today, will be changing more rapidly than now; and it will have jobs only for the well trained. I quote Whitehead, again, who in 1912 made a highly prescient observation in this vein:

> In the conditions of modern life, the rule is absolute, the race which does not value trained intelligence is doomed. . . . Today we maintain ourselves. Tomorrow science will have moved forward one more step, and there will be no appeal from the judgment which will then be pronounced on the uneducated.

Fortunately for our future, this fact is now generally appreciated. Scholars and educators, in increasing numbers, are being drawn to creative educational activities. The government, too, as one can see from the imaginative programs President Johnson is proposing, fully recognizes the need, and there are even many signs that the Congress is prepared to back them. If this hopeful trend is sustained in future years, our educational system has a good chance of meeting the increasing demands of our complex society.

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DAVID HAWKINS

The Informed Vision: An Essay on Science Education

In spite of the world-transforming consequences of science, we treat it mostly as a kind of external entity or power. Corporations invest in it and governments subsidize it, but not for its inherent quality as a human interest or engrossment, not for the way it can inform the human vision. Some learned and sensitive persons, poets or metaphysicians or moralists, view it with alarm as though it were a kind of epidemic. Some, like Donne or Pascal, confess the illness in themselves as they decry it; others manage to be model outsiders. Today, it seems to me, the question of the place of science in education has a special significance. To illustrate this, let me begin by stating a sort of anthropological thesis about the mutations of culture.

The thesis is that human societies have always specialized themselves. "Specialized" is used here in the most literal sense, what biologists call speciation. Societies have been like different biological species, each of its own kind. Part of this specialization is adaptation to geography and livelihood, but that part by itself is never unique. Part of the specialization is creation rather than adaptation, the elaboration of a way of life beyond evident necessity, including much that is expressive and ornamental. A well-ordered society manages, in one or another of many ways, to hold up before itself and to dramatize, to celebrate, the means and manners of its own life. We have many expressions of this sense of involvement and commitment, this condition of happiness. One is to speak of being at home in the world. This means, of course, that we very well understand the opposite condition of non-involvement, the many moods of alienation. But even this understanding is elaborated in myths and metaphysics. Part of coming to terms, of being at home, is in the sheer familiarity of the environment and in the sureness with

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which one lives and walks there. In his moving account of the lives of forest Pygmies,[1] Colin Turnbull recreates the sense of the forest as home—which is so essential to Pygmy culture—and the Pygmies' veritable passion for this domesticity, reaching a high religious expression in their great forest songs. Turnbull obviously fell in love with Pygmy life, and I suppose some of the sterner sect of anthropologists accuse him of lack of objectivity. But some things are best known by falling in love with them.

It is against such a background of comparison that I wish to discuss science in our own education. The world we live in, the world we must accept as home, is a strange world, indeed, by the measures of Pygmy life or by the measures which most men of any other time and culture could supply. We have transformed the surface of nature; in a figurative as well as literal sense we have cut down the forest. But even if we do not like some aspects of our cities and their circulatory systems, we built them ourselves, and they, too, reflect a good deal of domesticity. The important kind of estrangement in our existence, or so it seems to me, is not at this level. It derives from the fact that this extraordinary technological and material evolution of the last century or two—which should be visible even from Mars!—expresses a way of life and thought that has been genuinely available only to a minority among us. To the rest it is, in essence, an alien affair. Each innovation it has produced tends to pass, therefore, from admiration to boredom, without any intervening stage of comprehension and without the enjoyment which only comprehension can release.

Examples of this can be easily found. The actual air is, in fact, a rich example. To "go by air," as so many of us increasingly do, is just that kind of deprivation if we suffer it without a certain background of experience and involvement—and we go from excitement to boredom very quickly. What is the missing ingredient? There are many, from the intuition of the symmetries of thrust and lift formulated in such beautiful simplicity in the language of mechanics, to the complex interactions of wing and atmosphere. But more rudimentary than the dynamics of flight, there is a missing intuition about the air itself, and about its fluid reality. We know from work with children (and adults) that primitive man's indecision about air is still very much with us. Is air a kind of fullness, or a kind of emptiness? Some casual experience fits the one answer, some the other. Have you ever weighed a batch of air, or played with a plastic clothing bag half full—or half empty—of the stuff? From the

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dearth of such experience the intuitions of air's weight or inertia are very feeble in most of us. And what of that glorious amazement that burst upon the world of the learned when Torricelli confirmed Galileo's induction of the possibility of the vacuum with his barometer, and came to the realization that we swim in an ocean of air surrounding the globe? At some upper levels we "teach meteorology" with learned words about lapse rates and dew points and the taxonomy of clouds—to people still mostly lacking any acquaintance with the rudiments. I have not meant to exhaust the esthetics of flight and atmosphere. That takes more than a note, more even than St. Exupéry. But all of it is permeated with the affections of science—cloudscape, the color gradients of the earth and atmosphere, vapor trails, the rainbowed shadow of the plane, the sight of the great solid planet revolving below, and, above all, the human involvement in a biologically alien medium, in organization, detail, decision.

Nor does the relevance of science fail when we go beyond the esthetics of flight—as we of all people must—to St. Exupéry's preoccupation with this very science as armorer of mass destruction. He loved the creativity of science but not its vision of the world. He shared, I think, the alienation that I speak of[2]—of a world that will accept science to arm its military enterprises, but not yet to inform its vision.

Another example is light—the essential element of astronomy and, in the end, of so much of physics. It has been an amazing discovery, to me at least, that many adults have no firm intuitions of even the geometry of light and shadow. Like most young children, they cannot predict a shadow before the light is turned on. Mirrors are common in our lives, yet the symmetries of reflection are but little known. And how many people have ever played with pinhole images, watched the colors in the bevel of a mirror, or seen the daytime shadows moving? How many see the moon as an illuminated sphere, and sense from it the direction of the sun? In spite of all the discussion of the marvels of space, very few of us have any instinctive orientation on the earth, let alone in the solar system. Knowing that vehicles are on their way to begin photographing Mars, how many among us can find that planet tonight in the evening sky, and spare its mysteries a thought?

Then there is the matter of scale. Astronomical intuition demands at least a sense for that hundred million miles that approximates our distance from the sun. The stretching of the intuitions of

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scale is one of the characteristic accomplishments of science, both toward the large and toward the small. Yet as a firm possession this sort of simple intuition is rare except among the learned. Time as well as space demands it. Suppose we were to list the sorts of happenings we knew, that required times of the order of a thousand years, a hundred thousand, ten million, a billion. They are all around us, but the book is closed to most except to loving geologic eyes. The world of the solar system, which we now are committing ourselves to explore, and thus one day to feel at home in, *demands* the intuition of such a time scale. For we and the other planets have existed together in the same sunlight for a few billions of years, but otherwise completely isolated from each other. Such is the characteristic time of our own biological development; it is an evolutionary measure, correspondingly, of our separation from the other planets. Yet we talk and act, sometimes, as though we might just move in!

The Greek dramatists defined the sin of *hubris,* the sin of men who dared to be more than men, to go beyond man's place in the fixed order of things. "Being at home" for them was not only a state of assurance and familiarity, but of residence at a literal cosmographic and moral address. By their standards we do, I suppose, commit the ancient sin. But there is another sin we are in danger of —I think it is the same one, with definition purified—which is that of Moral Tourism, going to new places with the firm expectation of proper accommodations and a readiness to blame the natives if it turns out not so. I mean this in relation not only to the moon or Mars, but to all those extraordinary novelties we are gaining the power to encounter in our exploration of nature: of fissions and fusions, of the ecological turmoil that follows in the wake of our economic development, of our power to modify the genetic substrata of life. Even the planetary explorations are likely to have, for all our future, the most extraordinary consequences. Yet we began them in a competitive frenzy and continue them in budgetary tranquility, without appreciable excitement or debate. Because of the lack of any intervening comprehension, the idea of the space vehicle, like that of the airplane, will, I am afraid, pass too quickly from the stage of romance to that of ennui or alienation. And in this state we are, as St. Exupéry said, dangerous.

Some will object, perhaps, that this is all a gross exaggeration. By now there are many among us, a few per cent at least, who fully grasp and prize the way of science. The rest of us can trust

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them for advice and education. They are "experts." The word used to be a term of state, the state of being taught by experience—as a qualified technical witness, for example, in the courts. Now it has become a term of status. The scientific expert is still described as a person of purely technical competence, a knower of means rather than an adjudicator of ends. But increasingly and inevitably he is thrust into the latter position. Sometimes from vanity, I suppose, but certainly often from a heavy sense of social responsibility, he becomes a definer and a proponent of new social goals that science itself has made possible. Yet everything we know of history suggests that if this division in our society continues the scientific community will be subject to all the corruptions of caste and status. A world so deeply committed to science cannot survive with a vast majority of its population intellectually and esthetically alienated from science.

In my examples I have tried to imply a style of education that would permit correction, in our culture, of this basic defect. It has nothing in common with the need, so often put forward, to "produce more scientific experts." It has much more in common with the way of education described by Colin Turnbull in his account of Pygmy life. It is an education which begins in play suffused with enjoyment and evolves into an apprenticeship premised on commitment. Our needs are vastly different, I acknowledge, though it would be dangerous to assert that the Pygmy youth has learned much less. He has learned a great deal indeed, of the edible and inedible flora and the habits of deer or leopard, to walk in total silence, and to sing great songs. He could not survive, in that world, without a complex and subtle education. But what we must learn is in part more remote from the immediate environment, more abstracted and dependent on symbolic skills. And that is the challenge to our education: to recover for our world the ways of learning that are concretely involving and esthetically rewarding, that move from play toward apprenticeship in work.

To see what all of this means for us and our education I must turn to the discussion of science and what the philosophers have to say about it. I myself have spent a good many years in this occupation, which has recently developed a label for itself, the philosophy of science. But I have also been distracted from this pursuit by others. Jorge Luis Borges[3] quotes a marvelous sentence from W. H. Hudson, who said that in his youth he often undertook the study of metaphysics, but happiness always interrupted him. One of my own interruptions has been science, science unphilosophically itself; an-

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other has been science teaching and, most recently, curriculum development for elementary schools.

Attempts to characterize science, as is true of all new things, have come mainly by analogy with other occupations and their products. Exploration, food-gathering, architecture, weaving, playing games, map-making, book-keeping, composing, all have played their part as analogies in the attempt to describe the processes of science or define its product. The one I want to single out here is the analogy of art, of art taken rather generally and therefore with a good deal of internal variety. Like all the other analogies, it will break down at various places, but I have selected it because I think it does not break down in one very important place—school.

A natural association with the word "art" is the sense of an implied spontaneity in a work of art or the enjoyment of it. In one of his most important writings on education (which, incidentally, does not contain the word in its index), John Dewey says this about spontaneity of artistic expression:

> Works of art often present to us an air of spontaneity, a lyric quality, as though they were the unpremeditated song of a bird. But man, whether fortunately or unfortunately, is not a bird. His most spontaneous outbursts, if expressive, are not overflows of momentary internal pressures. The spontaneous in art is complete absorption in subject matter that is fresh, the freshness of which holds and sustains emotion. Staleness of matter and obtrusion of calculation are the two enemies of spontaneity of expression.[4]

If one were to try to formulate the quality of any achievement of learning, at its best, one could hardly find a better formulation than "complete absorption in subject matter that is fresh, the freshness of which holds and sustains emotion"—or of the opposite quality, in "staleness of matter and obtrusion of calculation."

But is it really permissible to talk about spontaneous expression in science? To be sure, the approved style of scientific communication could hardly be called lyrical. But we should not forget that *human* expression, for Dewey, is no mere display or outburst; it is a synthesized achievement compatible, as Dewey goes on to say, "with any amount of labor provided the results of that labor emerge in complete fusion with an emotion that is fresh." Emotion, then: surely science is concerned with knowing, not with feeling; with expression of fact, perhaps, but not with personal expression. Science is concerned with prosaic truth, objectively defined, publicly testable and emotionally neutral. Surely I have misled myself in

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thinking of science as a form of art, carried away by some wild philosophical conceit.

I know the reason for my error; it is a group of recollections and anecdotes of times in school when it did seem that children, after rather complete absorption in scientific subject matter that was fresh, emerged with some unifying and spontaneous expression of insight—and surely not without emotion. I vividly recall one child, for example, who seemed to acknowledge the reality of the great sphere of the earth as though for the first time—not from a transatlantic jet, but in the schoolroom. After long absorption in the behavior of a string-and-steel-ball pendulum, he suddenly saw it as doing *something* when it was just hanging, its motion spent. "Pointing toward the center!" The little sphere and the great sphere were joined in one act of knowing, fresh and emotion-sustaining. The only comparable experience of my own I can remember now was a recent one, when in the path of eclipse totality I became emotionally very much involved with the onrushing shadow, and quite literally felt the presence and opacity of the great occulting sphere, the moon. Surely I felt this only because, as an amateur, I have spent many hours absorbed in subject matter, exploring the moon visually and learning to picture it on the scale of earth and sun. In my case the experience came late, and I prize it; in Jeff's it came at age ten and released a flood of remarkable questions and investigations that, when we last met, was carrying him straight toward the world of Isaac Newton.

Perhaps my analogy is not lost, after all. Perhaps it is just that our usual account of science is a sort of timid and official tone, correct as far as it goes, but leaving out the personal act in favor of the public process, the privately consummated experience in favor of the social achievement. And perhaps those who immerse themselves deeply in scientific pursuits do so because of their initial attraction to science and then *learn* to prize the dry, austere, and impersonal mode of expression, as one which they think best keeps a sort of subject matter fresh, and best holds and sustains the emotions appropriate to that subject matter. From this point of view there is much about the style of scientific thought, expression, and teaching that we need to reexamine. Later in *Art as Experience* Dewey refers to the fact I have already discussed above, that science

> . . . as now practiced is too new to be naturalized in experience. It will be a long time before it so sinks into the subsoil of mind as to become an

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integral part of corporate belief and attitude. Till this happens both method and conclusions will remain the possession of specialized experts, and will exercise their general influence only by way of external and more or less disintegrating impact upon beliefs, and by equally external practical application.[5]

Is it possible that the style of scientific expression and communication depends more upon its cultural *newness* than upon the inherent necessities of the case? If we imagine a society in which what we call science has sunk deeply "into the subsoil of mind," what would be its style of expression? Would science any longer even be *called* science? The above passage occurs in the context of a discussion of the isolation of fine art from the vital centers of community life, which Dewey, like many other critics, attributes partly to the "external and more or less disintegrating impact" of science and technology upon older beliefs and ways of life. More than any other recent philosopher—except possibly A. N. Whitehead—John Dewey spent his life attempting to naturalize and humanize the scientific way of life and thought. In his educational philosophy (best stated in his non-educational writings) he saw deep affinity between the style of research in science and the natural probings and explorings of children. In his strong desire to reinforce the latter as the basis of all true education, Dewey likewise was moved by the belief that in this way the external and disintegrating influence of science would be transformed into an internal and creative one, penetrating into the subsoil of mind. Long before the current "two cultures" debate, John Dewey had formulated the dichotomy for a generation of American thinkers and school reformers and had set forth a program to heal the split. This program was to look beneath the surface of achieved scientific knowledge as dogmatically formulated in textbooks (and popularizations) to the underlying life of scientific inquiry, to the scientific method.

In good part because of the influence of Dewey, a generation of American teachers was brought up with the slogans and shibboleths of the scientific method, and in not a few centers schools were started which undertook to demonstrate the feasibility of an education centered around practical involvement of children in enquiry and creative expression. For a time, some of the public schools became more or less involved, and "progressive education" was *the* term of praise.[6]

Judged by the aspirations of the originators of the movement,

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very little is left today—little of the slogans, and even less of the practice. The most recent wave of educational reform has been motivated in part by a stern emphasis upon "the return to subject matter," both in the classroom and in the training of teachers. Are we to conclude, then, that the Deweyan program of education has been tried and failed? I do not believe it has really been tried; but I also do not want to declare the experiment irrelevant. At their best, the progressive schools were excellent; but the best was rare. At their worst, they may have justified the abuse heaped upon them by scornful critics. There are, I believe, two conclusions which can be extracted from the history of this institutional movement. One is a conclusion of theory, one of practice.

The theoretical conclusion I would urge is that the key conception of scientific method, of what Dewey called "the supremacy of method," is subtly wrong. Those who have read Dewey's more philosophical and less propagandistic writings will know that he is not always guilty of any real separation of "method" from "content." But there are some truths that require at least *two* sentences for their utterance, and slogans are generally expressed in one. The first truth may well be that the art of scientific inquiry is educationally more fundamental than the facts and principles established by that practice. But the second truth, no less important, is that the art cannot grow except by what it feeds on; and what method feeds one, the whole source of its power and authority, is the very order and organization of the world it investigates. The mind equipped with method and no content is not more than the grin of a Cheshire Cat, an absurdity of misplaced abstractions. Dewey knew this, but he did not relish and emphasize it. So now we are in danger of new slogans, which in the re-emphasis on content will assume that method grows spontaneously out of improved "subject matter."

Try as I may, I cannot put it all in one simple sentence. "Method is the *use* of knowledge to *extend* knowledge." But then I must add, with the John Dewey of *Art as Experience,* ". . . through complete absorption in subject matter that is fresh." And this leads me to my practical conclusion from the failure of progressive education to win its way into a permanent place in education. Where that movement succeeded, it did so because the world of children's exploration was amply provisioned with subject matter they could explore well, could penetrate deeply. Where it failed, it did so because the freedom for active involvement was inadequately provisioned. This inadequacy was often concealed by a preoccupation, illegitimate in

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the *absence* of provisioning, with the maturation of the child personality. "Freedom of expression" was often seen as a good in itself, unmindful of the fact "that man, fortunately or unfortunately, is not a bird." Faced with the all-too-real maladies of psychic development in our children, and influenced by popular Freudian beliefs about the curative effects of "permissive" adult behavior, some few schools no doubt earned that indignant reflex utterance that "freedom is not license!"

It is my impression that the success of the progressive education movement was greatest for the earliest years, where its ideas and programs merged with the already solidly-based practical tradition of the kindergarten, imported to these shores a half-century before, with philosophic roots, many of them, common to Dewey's own background. Here there was not only a style of teaching that involved children deeply in subject matter, but the subject matter grew with the style—water, sand, clay, paint, good infant literature, the cultivation of story and song, carpentry, lenses, prisms, magnets, blocks, the house of packing boxes and orange crates, soil and seeds, animals, the dance, and all the rest. I do not believe that this tradition failed at all; its influence has been reduced by erosion (sometimes to the vanishing point), by pressures for thin mechanical programs of "reading readiness," "number experience," and the like, most of which tend to reduce the very readiness they seek to cultivate.

The moral, then, is that absorption in subject matter requires a major effort of provisioning for that subject matter. If children are going to emerge from our schools secure in the practice and enjoyment of the arts of inquiry, it will be only because they have long practiced those arts, in engagement with the world around. In relation to science, this means that their involvement with it will have been of a kind such that we can truly say it has penetrated the subsoil of their minds and earned their loyalty because it has liberated them from the boredom and sophistication that come with living in an unexamined world, because it preserves the freshness of subject matter and sustains emotion.

In my own way, then, I agree with the present emphasis on a "return to subject matter." In the newer science curriculum developments, there has often been an emphasis on individual work, by children, that is laboratory-like in its style. This seems to me to be of very great importance. It constitutes a delayed recognition that the subject matter of science is not, except in a derivate sense, to be

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found in books. The subject matter of "the liquid state of matter" is the liquid state of matter, and we had better sometimes have some of it in the classroom. Along with aprons and mops as needed! The subject matter of sea animals may make more sense for coastal schools than inland, but if it makes sense inland it will be because the provisioning of salt-water aquaria has been reduced to a simple routine that schools can and will maintain. The subject matter of atoms is a puzzle. There are plenty of them, of course, in every classroom, but there must be a long course of evolution, and much penetration of experience into the subsoil of the mind, before the world of atoms will prove to be fresh and absorbing subject matter.

The beginnings are there in the kindergarten, in sand and sawdust worked with, and then seen with magnifiers. They are there in the drops of food-coloring billowing out into the water. Do the dye and the water really *mix*, or is it like a tangle of colored threads that just get thinner and more numerous until you can't see them any more? An honest answer is not yet available from nature, at the elementary laboratory level of investigation. But what a question! Later there is more, in the disciplined use of serial dilution, of saccharin and quinine and vinegar, of dyes and yeast suspensions, or Chlorella. Still later come the beginnings of simple quantitative chemistry, after the uses of quantity have been elaborated in other and more urgent contexts, and after the hand-lens and microscope have led to Lilliput and even smaller worlds. The direct evidence of chemical atomicity is not to be found in the elementary-school laboratory. Radioactive scintillations from a watch-dial? Perhaps, but what absorption in previous subject matter is implied, to see these as atomic events! The philosopher and physicist Ernst Mach disbelieved in atoms through all the evidence of nineteenth-century chemistry. What convinced him, in his old age, were the phenomena of radioactivity. I would not demand this much for children. Mach was stubborn. The important thing is not to *prove* the reality of atoms, but to bring them alive in the imagination and intellect. Otherwise, why push? To please parents with the appearance of understanding? Or is this high-school-chemistry-readiness?

I have tried to suggest what laboratory style might mean in elementary-school contexts. Peter the Great said he would open a window onto the West, and the elementary-school laboratory might do as much, onto the world. But nowadays the pressures are toward the windowless school, and I have very honest doubts. The laboratory traditions, in college and high school, are in many ways not

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encouraging. Nor do I wish to underestimate the difficulties in avoiding a style of laboratory work limited, as in fact our laboratory traditions mainly are, to the attempt to certify the truth of previously announced propositions, not yet *understood* by the majority of students who, recipe book in hand, dutifully perform.

I know the difficulties are real because I have perpetrated the crime myself as a college science teacher, and I have done it often rather than seldom. It is certainly possible to program work, in some kinds of laboratory science, so as to rob it of almost all romance and reduce it, nearly, to the status of rote—perhaps not quite, if only because a student very soon discovers that the experiment seldom works the way he has been told it will, that the "best" answers still come from the book rather than from his data. In some secret way, perhaps, he learns to mistrust the book. Or does he draw the opposite conclusion, that, in this great world he is being educated into, nature is to be taken with a grain of salt?

A partial explanation of these difficulties can be found, I think, in the psychology of us who teach science. In some measure, by some accidental pathways not commonly followed in our age, the culture of science has penetrated at least a little into the subsoil of our minds; we have pursued it much beyond the average. But from this there are two results, contradictory to each other. One is that we have some art in scientific inquiry; we have been absorbed in scientific subject matter and we know the fruits in our enjoyment of them. The other is that we have proven or declared ourselves, and are certified to teach. The consequence is social caste. We are the knowers, the explainers. Nothing moves us to such generous efforts as to be asked for explanations. Shrewd children, even shrewd adults, learn to ask these flattering questions, though their interest is slight and passing. For the deeper the perplexity, the more burning the curiosity, the less children or adults seek prompt explanation. When you have exhausted your own resources and still fail, *then* you will go for help. If you go too soon to an explainer, he does best to turn you back on your own resources, or to direct you toward acquisition of new ones.

What is true of the initiates is true, also, of those whose misfortune it is to teach science without any conviction of inner illumination. Here is the book, they are told, or the syllabus, or the teachers' guide. Now teach! The style is set for them; they know they are supposed to teach, to give explanations. And we, alas, the devotees, the mystics, have set that style.

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I mean no offence to men, only to methods. There is of course a place for explanations, for didacticism in all its plumage. In the last part of the curriculum, in the homestretch toward professional degrees, we may even glory in it. The apprentice has made his decision, and we must make a tough professional of him and try him by ordeal. But our motives are still suspect, and even here, I think, there can be radical improvement. What distinguishes science from the personalized arts—as poetry, or painting—is the essentially social nature of its product. The cathedral that took a century to build is more nearly the model. No single architect planned it, though the mark of individuality is everywhere, of craftsmen absorbed in a common subject matter, whose expression sustains collective emotion. But here none of the analogies is really good. The art that is science is a distinct genre. Its constructions are not buildings, not machines, not instruments, though these may be among its modes of expression—as may be the textbook and the syllabus. The essential construction of science is a personal way of being related to the universe. This way has many expressions and can have many more, in conduct, artifact, or text; but it is primarily a way of knowing, and the knower is always the artisan of his personal knowledge. The social character of science is misrepresented when we forget this artist, pretending that the depersonalized social expression is the essence. Every art has its constraints and disciplines, and one of the disciplines of science is the demand for logically coherent formulation and noise-free communication. Hence the syllabus and text, hence the refinement of terminology. Yet, ironically and sadly, it is this very discipline which raises the barriers to communication in our schools. The letter of the discipline has too often been taken to be its substance. Here as always the letter kills, especially in the early and crucial years. The tight formulation and logical sequencing must be learned, but they cannot be learned first. They will be learned only when a knower comes to prize them for their power of liberation and guidance. What comes first is absorption in subject matter. No one learns by being led blind along a path he cannot begin very soon to see for himself.

And here I come to what seems to me to be the crucial and largely unsolved problem of science education (or of any education). Method consists in using knowledge to gain further knowledge. Yet what each individual knows that he can use in this way is, at any moment, a highly individual affair. In reducing our experience to order, the distance we must travel to achieve any com-

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ponent of this order is not a well-defined quantity; for there are many paths to a goal of understanding, and along any path there are *many* available important goals. Logically considered, the relations among the ideas which bring order to our experience constitute a complex network; ideas are not stations along a single road. In this psychological world, what we mean by distance along a given path can be measured by the number of probings and testings, of discriminations, we must make to traverse it. Paths already well-trodden are short *because* they are well-trodden. For this reason the patterns of optimal learning are highly individual. In the early and deep learning that goes with play, some of the conditions for approximating these individual optima are present. Since there are so many important things to be learned, the direction of exploration is not critical. What is learned will add to the power of later learning. What is important is the confrontation with materials which play can exploit and incorporate—absorption in fresh subject matter! From what we now know of informational processes, even machines designed for pattern recognition and classification will function most efficiently—when dealing with a very complex system of data—if they are deliberately programed for such "nondirective," in some respects even random, "Monte Carlo" exploratory behavior. In spite of the anxieties about machines in our culture, it may be that the machine designers are closer to an appreciation of what is involved in human learning than are those circumscribed by the simplistic traditions of behavioristic psychology and "programed learning."

But there comes a time for harvesting, gathering, organizing, even programing, and here individual learners must be drawn together under a common discipline. In our schools, this time comes much too early. Or better, it is too little preceded and followed by periods—long periods—of individualized and diversified work of a more exploratory and self-directed kind. In being so critical of the prevailing style, however, I do not want to make an opposite error, of forgetting that apprenticeship phase of their education when the young Pygmies go out on their first hunts or build their first houses under adult direction. It seems to me that in our context the great teaching art must prove to be the art of combination. We must learn better to instruct children when, after absorption in subject matter, they communicate by their behavior those directions which they are prepared to find meaningful because they themselves have begun to define and seek them. And then there is the opposite tran-

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sition, when formal instruction has brought children to new levels of understanding and interpretation: to open again the door to less directed probing and testing at these new levels—and thus to consolidate what has been learned, to use it for further learning.

There are certainly some superbly resourceful teachers among us who practice and understand this art, although perhaps they are not articulate about it in the context of educational discourse. Can we identify them, we who want to know the art better? And can we go and watch, and thus learn? And can we, after watching, begin to help them with the provisioning, with plants and animals and laboratory equipment—and ideas! Can we then find ways to resonate, to amplify, to strengthen the apprenticeship of other teachers? The job is not easy on any scale. On the scale I have tried to suggest, that of a whole society in which the esthetic meaning of our commitment to science will have penetrated the subsoil of the human mind, it is difficult indeed. But on this scale the motivation should also be strong to find meeting places where these present realities of our future, children and science, may be brought more happily together.

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JEROME KAGAN

Personality and the Learning Process

THE CENTRAL concern of both educator and psychologist has always revolved around the twin questions of "what is learning?" and "how does it occur?" Despite years of thought and many hundreds of laboratory investigations, we are still not able to provide logically commanding and intuitively attractive answers to these questions. The gnawing sense of bewilderment that surrounds these issues is attenuated a bit if one assumes that if a child attends to information presented to him he is most likely to learn something about it. If the child's attention toward the written or spoken symbol is guaranteed, some learning is likely to occur. Put aside any temporary complaints to this presumptuously simple proposition and consider the directive it implies. This idea leads us to inquire into those psychological factors that promote or obstruct attention to symbolic material. The focus on the child's attention rather than on the special effect of a particular book, television program, or curriculum delineates a principle that can guide the preparation of material for intellectual consumption by the child. The principle states: the learning of a new rule, word, or bond between two previously unrelated elements requires a certain level of prior cognitive resources and sustained attention to the material to be learned. The level of attention is determined by a variety of factors, many of which have been regarded traditionally as personality variables. These personality variables include concepts like motives, expectancies, sources of anxiety, defenses, and standards, each of which exerts some control over the child's distribution of attention in a problem situation and governs the initiation of and persistence with mental work. These intrapsychic forces determine how long the child will work at the learning of a new task, how difficult a task he will attempt to master, and how he will interpret success or

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failure. The most relevant concepts are described in the sections below.

The motive for acceptance and positive evaluation by parents and parent surrogates. The desire for praise, affection, and more symbolic signs of positive evaluation from adults leads the child to work at the mastery of new skills in order to obtain and retain these rewards. To many children of four or five years of age learning is a socially motivated enterprise, especially when the tasks do not have any clear relationship to the instrumental skills the child uses every day. That is to say, learning how to play marbles and learning to ride a bicycle have strong significance for the child because of their positive valuation by peers and because the child is able to assess his progress in gaining mastery over them. However, reading, spelling, and arithmetic do not always share these extra advantages. Learning multiplication tables is intrinsically boring to many children. The child becomes interested in acquiring this skill because adults whom he admires praise and reward him for that mastery. The receipt of adult rewards for such mastery is interpreted by the child as signifying that he is appreciated by the adults who administer these favors. The value of these favors depends on the sex and age of the child and the nature of the task. In general, adult praise is more significant for girls than for boys, for younger children than for older children and most relevant when the task to be mastered is related to previously valued instrumental skills.

The motive for differentiation. There is a general human tendency, present from the preschool years on, to accrue attributes that differentiate the self from peers and siblings; to develop characteristics that allow the person to label himself in some unique way. The writer recalls young children pointing with pride to their surname in the telephone book and saying, "We are the only Brewsters in the telephone book." The child's understanding of who he is derives, in part, from the skills he has mastered. The specific skills he chooses for mastery are determined by the values of his subculture. Since our social community places heavy emphasis on intellectual mastery, most children choose this route for self-definition, and their striving for excellence in the academic situation is partially in the service of the desire for differentiation. Professor Donald MacKinnon of the University of California recently contrasted the personalities of architects and mathematicians who were judged to be extremely creative with those in the same occupation who were successful but less creative. One of the salient charac-

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teristics of the highly creative adult was his strong desire to be different from his peers, his yearning to produce a unique product.

The motivation to maximize similarity to a desirable model. Children and adults want to maximize similarity to adults who command power, status, and instrumental competence. The child desires these intangible goals but does not know how to obtain them. He believes, however, that if he made himself similar to the adult models who appear to possess these desirable resources he might share vicariously in their power, status, and competence. If these models display an interest in the mastery of intellectual skills the child will attempt to mimic such mastery in order to maximize similarity with the model and increase the probability that he will share in these intangible goals. The absence of this dynamic in many lower-class families is partially responsible for the fact that lower class children are less highly motivated to master intellectual skills. The lower-class child's inadequate performance in school is not solely the result of his parents' indifference to his school performance. Lower-class parents often exhort the child to work for grades and punish the child for failure. However, the lower-class parent is not perceived by the child as a person who values intellectual mastery. Thus the child does not view intellectual mastery as a likely way of gaining the adult resources of power and competence that he perceives his parent to possess.

It may seem inconsistent to state that the child has a strong motive for differentiation and an equally strong motive for maximizing similarity to an adult model. These two processes behave like a pair of opposing pipers that lead each individual through much of his life. One of the basic characteristics of man is his attempt to maintain a balance between the desire to differentiate himself from a larger group with less resources than he commands and an equally strong desire to make himself similar to a group who he believes possess more resources. Psychological development has a spiral form in which a child identifies with a group commanding desirable goals and, after maximizing similarity to that group, differentiates from it and passes on to the next identification, in an almost never ending seesaw struggle between maximizing similarity to one model and differentiating from another.

Expectancy of success or failure. Children quickly develop different expectations of success or failure in intellectual tasks. Unfortunately, the most frequent and prepotent reaction to an expectancy of failure is decreased involvement in the task and subsequent

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withdrawal. Educators have been guilty of minimizing the critical role which a child's expectancy of failure plays in shaping his behavior in a school situation. An extreme variant of the progressive movement in education assumed that the child, if left to his own devices, would seek the best possible intellectual diet. This assumption proved only partially true, for it ignored or refused to acknowledge that a child as young as six years of age is aware of his capacities, has clear expectancies of success or failure, and wishes to protect himself from the anxiety that follows failure. Many six-year-old children with a strong desire to learn to read, but with an equally strong doubt over their ability to do so, do not spontaneously approach books, but withdraw to the less threatening tasks of coloring and pasting. The child's motives are contingent upon expectation of success or failure, and motives are sloughed or adopted with zeal, depending upon the degree to which the child believes he can attain the goals that gratify the motive. Persistence at task mastery hangs delicately on the balance between hope and fear.

Anxiety derived from conflicts over learning. There are many relevant conflicts that inhibit or facilitate the learning process. These include excessive competitiveness, desire for power over others, assumption of a passive posture with teachers, anxiety over dependency, and sex-role conflicts. Let us consider each of these briefly. The school situation, in most public-school settings, is essentially a competitive enterprise. The child who desires good grades, for whatever reason, realizes he is in competition with his peers. The teacher organizes the classroom situation as a competitive arena. In such a context the child with a strong desire for excellence will entertain wishes that those who are his closest rivals will suffer some misfortune. The child who is vulnerable to guilt over these hostile thoughts may become anxious and place some inhibition on his attempts at excellence. This conflict over the hostile flavor of competitive wishes is one reason that young adolescent girls perform less well in high school and college than they should. The female in our culture is more disposed to guilt over hostile wishes and inhibits intense academic effort as a result of this conflict.

An equally forceful conflict is experienced by boys during the elementary school years. The primary grades are characterized by a pressure for conformity and for a passive posture vis à vis the teacher. The six- or seven-year-old boy is in the process of identifying with adult males and experiences some conflict over assuming an overly conforming or passive attitude with the female teacher. The

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imposition of a passive role creates anxiety and conflict, and he attempts to fight assumption of this role. The unruliness, distractibility, and general mischievous behavior of second-grade boys is related, in part, to conflict over the passivity imposed by the school situation.

A final conflict is more pervasive and involves the relationship between sex-role identification and academic products. It is well documented that problems requiring analysis and reasoning, especially spatial reasoning, science, and mathematics problems, are viewed by both sexes as more appropriate for boys than for girls. As might be expected, girls perform less well on such materials. In one investigation, adolescents and adults were presented with problems involving mathematical reasoning, and the males obtained consistently higher scores. However, if the same problem dealt with "feminine" contents such as cooking or gardening, the females did much better than if the problems dealt with guns, money, or geometric designs, although the reasoning operations were identical in both problems. The typical girl believes that the ability to solve problems in geometry, physics, logic, or arithmetic is a masculine skill, and her motivation to persist with such problems is low. Her decreased involvement reflects the fact that her self-esteem is not at stake in such problems. In some cases she is potentially threatened by the possibility that she might perform with unusual competence on such tasks, for excellence is equated with a loss of femininity.

The sex-typed character of knowledge is most evident in the vocational choices of young adolescents. A recent national survey asked several thousand high-school students about their probable major in college and future occupational choice. The sex-typed character of their choices was already evident in the ninth grade where twenty-five per cent of the boys and only three per cent of the girls selected the physical or natural sciences, whereas three per cent of the boys and thirteen per cent of the girls chose elementary- or secondary-school education as future vocations. An additional reason for the lowered motivation and performance of girls in science and mathematics rests with the fact that a girl's sex-role identity is more dependent on her ability to attract and maintain a love relationship than it is on her academic skills. The male views academic excellence as a necessary antecedent to vocational success. Since such success is an essential component of the male sex-role identity we would expect the adolescent male to be more highly motivated to master those tasks that are linked to his vocational

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choice. A girl is more likely to work to gain the acceptance or approval of her teacher and parents, while the boy uses mastery as a test of his personal potency. More boys are oriented to figure the task, more girls to figure the teacher.

Although an intense involvement in the sciences and mathematics is more characteristic of the adolescent and adult male than female, this differential in motivation is not necessarily the case in the primary grades. In the early years, girls typically out-perform boys in all areas, and the ratio of boys to girls with reading problems varies from three-to-one to six-to-one. How can we understand the fact that the academic performance of girls is superior to that of boys during the primary grades but gradually becomes inferior during adolescence and adulthood? Two reasons have been mentioned: boys eventually link vocational success with academic performance and their lower anxiety over competitiveness leaves them freer to strive for superiority over their peers. A final reason for the increasing academic superiority of boys rests with the change in perception of the sex-typed character of school and academic work. First- and second-grade boys have more difficulty than girls in mastering reading and arithmetic because the boy perceives the school atmosphere as essentially feminine. The six-year-old boy is striving to develop a masculine sex-role identification, and he resists involvement in feminine acts. By the time the boy is ten or eleven, he recognizes the relationship between a vocation and school work, and his resistance lessens. The atmosphere of the primary grades is generally viewed as feminine because the child's introduction to school is mediated by females who initiate the activities of painting, coloring, and singing. Most teachers place a premium on obedience, decorum, and inhibition of aggression and restless motoricity. These values are better tailored to girls than to boys and it is not surprising that children view the school situation as more feminine than masculine. Also, there are strong semantic associations between the dimensions of "masculinity" and "femininity" and specific areas of knowledge for most adult members of western culture. This is an unfortunate marriage for one would hope that knowledge would retain some neutrality amidst the warring factions of the mind. It may be possible, however, to alter this associational link between domain of knowledge and the sex roles through modifications in the procedures and atmosphere in the elementary schools.

Standards of performance with respect to intellectual tasks. Children differ dramatically in the standards of performance which they

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set for themselves. Some children decide that performance just a bit above average for their class is adequate to meet their standards; others demand of themselves the top position in the class. The child's commitment to work and persevere will be a function of the standard that satisfies him.

Preferred modes of dealing with hypotheses and information. A final construct of relevance involves individual differences in the speed with which hypotheses are selected and information is processed. It has been established that the tendency to be impulsive or reflective in selecting ideas for action is an extremely stable trait that generalizes across a wide variety of tasks. When faced with a problem suggesting multiple possibilities for solution, some children select the first answer that occurs to them, and, in many cases, their solution is incorrect. Others tend to brood a longer period of time, considering the differential validity of the various solution hypotheses that occur to them. These children are called reflective, and they are usually more accurate in their first reply. It should not be surprising that reflective children do better on problems of inductive reasoning, make fewer errors when learning to read, and are regarded by the teacher as inhibited.

These constructs deal with some of the major forces that exert strong control over the involvement of children in learning new materials. Now let us turn to the ways in which these ideas can help resolve the question of whether discovery learning, that is, learning through inductive reasoning, is more effective than teaching through exposition. Should the teacher give the child examples and allow him to infer the rule or should she present the rule first and allow the child to explore the relevant examples?

A common strategy in polarized debates of this type is to reply, "It depends on the child, his sex, his age, his personality." This reply is offered not because we wish to evade the issue, but because it appears to be the most reasonable posture. Individual differences in behavior are the rule rather than the exception, and there are few environmental intrusions that have the same effect on all children. There is always interaction between method of presentation in the classroom and the psychology of the child with respect to the mastery of intellectual material. Let us consider, therefore, the pros and cons of an inferential *versus* a deductive approach to the presentation of learning materials to children.

The following arguments are often presented in support of the inferential or discovery method of teaching:

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Discovery learning requires more involvement on the part of the child and therefore greater attention to the component materials being presented. Since the discovery strategy creates maximum attention and involvement it should lead to more efficient learning.

Discovery learning requires the child to make an intellectual effort, and this effort leads to an increase in the value of the task. It is reasonable to assume that activities become valuable to the degree to which effort is expended. In fact, many of us have had the experience of being more involved in a set of data we collected personally than in data we might regard as more "significant" scientifically but which were collected by other people. Effort increases the incentive value of the enterprise, and motivation is created or increased.

Inferential learning is likely to increase the child's expectancy that he is able to solve problems autonomously. The discovery method maximizes the likelihood that the child will learn a self-descriptive statement having the following content: "I can think." One of the primary aims of education is not only to teach the child some particular set of cognitive rules or structures, but also to teach him confidence in his ability to think creatively about intellectual problems. The method of discovery is more likely to accomplish this end because it requires the child to infer a major principle without excessive guidance from an external agent.

The method of inferential learning helps children who have a passive-dependency conflict with respect to the teacher. Some children, especially boys, have difficulty in a traditional school setting because of their strong conflict over a dependent orientation toward the teacher. Since the culture promotes independence in boys and creates a standard for independent activity, many boys experience discomfort and anxiety over a passive posture with female adults. The method of inferential learning requires and promotes a more independent attitude on the part of the child and should help those boys who are experiencing high conflict over passivity.

These are four possible advantages of the inferential method. But before being persuaded by these arguments, consider the equally compelling arguments against this method of presentation:

Many children do not have the initial motivation to exert the effort required to make inferences. The method of discovery requires a period of five or ten minutes or even longer during which the child is attempting to tease out a simplifying rule. For children who enter the task with high motivation this delay is not of much

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import. But for children of lower IQ and/or lower motivation who do not place high value upon intellectual mastery, the requirement of even three minutes of involvement without reward is too burdensome, and they are apt to withdraw from the task if success is not immediate. I have watched children with lower motivation in a discovery atmosphere, and their low threshold for distractibility is painful to witness. The method of discovery is minimally appropriate for children who enter the problem with low motivation.

Young children, especially five to seven years of age, do not have a sufficient appreciation of what a problem is or what a solution is, and the incentive value of making discoveries is not very strong. I refer here to an important developmental difference in the attractiveness of making inferences. Twelve-year-old children have already learned the joy of discovery, and for them the inferential method is inherently attractive. The seven-year-old is still acquiring the value of this activity, and many have not even learned to appreciate the nature of a problem. As a result they do not remain within the constraints of the problem and bring in aspects of reality which interfere with the problem solving process. The tendency to confuse reality with the artificial constraints of the problem is serious when one is trying to teach principles by the discovery method.

Impulsive children are apt to settle on the wrong conclusion in the inferential method and become vulnerable to developing feelings of inadequacy. The impulsive child does not reflect on the validity or probable accuracy of his hypotheses before offering them to the teacher, either orally or on paper. Since these impulsively derived hypotheses are apt to be incorrect, the impulsive child encounters a series of humiliating failures and eventually withdraws involvement from school tasks. The method of discovery is more appropriate for children who normally reflect on the validity of their hypotheses.

In sum, the method of discovery is most appropriate for highly motivated older children who might have high dependency conflict and who are inclined to use a reflective strategy. This method is least appropriate for younger children, especially those below the age of nine, who do not have high motivation to master intellectual tasks and who tend to be impulsive. Some aspects of these recommendations have research support, others must be tested in the laboratory, but each is a reasonable proposition.

There is not only interaction between the psychological organization of the child and the method of presentation, but also between

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the substantive content and the method of presentation. It would seem that contents that are tailored for discovery learning are disciplines containing principles that are usually induced through the proliferation of hypotheses. The proliferation requires a rich cognitive structure upon which the child can draw. The natural sciences and history are the best exemplars in this regard. Content areas for which the principles tend to be less obvious and for which the child does not initially have a rich set of cognitive structures gain less from discovery procedures; early mathematics is the best exemplar of this class. Considerable structure must be accumulated before the discovery method can work with profit.

Attention and the role of novelty. The theme of this discussion has centered on the directive role of intrapsychic processes within the child, processes which determine how much attention shall be invested in the mastery of particular skills. The organization and strength of these forces are highly variable among children, and this variability helps to account for the broad spectrum of intellectual competencies present in every school.

There is, however, one event that usually captures the attention of all children—at least temporarily—and the critical quality of that event is surprise. Novelty is one of the educator's most effective weapons in the battle against pupil apathy, for surprise temporarily recharges the attentional system.

The contemporary educational scene has generated palpable excitement over the benefits to be secured from manipulation of materials, books, curricula, and visual presentations, and there is a strong hope and unshakable faith among many who are exerting much effort and wisdom that herein lies a major solution to the ills that plague educational practices in our schools. In many instances the major catalyst behind improved performance is the novelty implicit in the change. Perhaps it is strategic to present the child with a method he does not expect, to pose a series of surprises along his educational itinerary, to violate his anticipation of what is to come—gently rather than with hammer blows—in order to keep his vigilance perennially high. A dean at a leading liberal arts college facetiously summarized this notion when I mentioned my apprehension about a recent radical change in the educational procedures of his institution. He replied to my ingenuous attitude with a reassuring laugh: "Don't worry, the novelty effect will bail us out." It would be unwise to derogate the role of novelty or to develop a coolness toward revision of instructional procedures because novelty

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rather than an abstract theoretical consideration provided the impetus for growth. We all seek the same goal—to teach the child the desire to sharpen his intellectual tools. We know too little about this delicate process to reject any tactic that might pierce the nightshade of ignorance that envelops the problem of why and how a mind grows.

Preparation of this paper was supported, in part, by research grant MH-8792 from the National Institute of Mental Health, U. S. Public Health Service.

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LAWRENCE S. KUBIE

Unsolved Problems of Scientific Education

I. *Preconscious Learning and the Neurotic Process*

ALTHOUGH FOR the most part we are aware only of the conscious component of our mental processes, we neither think nor learn consciously. In fact, conscious symbolic processes are not the major instrument for acquiring new information, for processing it in the brain, which is man's communications machine. Nor are conscious processes ever active alone. Day and night, sleeping and waking, there is an incessant interplay among three psychological systems (or "levels"), for which "conscious," "preconscious," and "unconscious" are familiar, recognizable, and not too inaccurate designations. The summated effects of the interplay among them implement all behavior, thought, purpose, and feeling in human life. There is abundant evidence, largely overlooked, that among these three the more pervasive, continuous, and dynamic is neither conscious nor unconscious, but *preconscious.*

This consists of a continuous and remarkably rapid stream of afferent, integrative, creative, and efferent activity, mediated by coded cues and signals, but without fully developed symbolic representation. It is what the Wurzburg school[1] used to call "imageless thought." It has also been called "paraconscious," "coconscious," "subliminal," the "fringe of consciousness," and finally "preconscious." This preconscious stream is fed by an incessant bombardment of afferent signals which arise both in the body and in the world outside. Only a fragment of these signals consists of conscious sensations; most are subliminal. Another source of data for the preconscious stream consists of active residual imprints from prior experiences. All afferent signals feed into the stream of preconscious internal processing, out of which come all actions, thoughts, memories, feelings, and anticipatory planning.

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Conscious symbolic processes sample all of this activity: that is, the incoming signals, the preconscious processing, and the outgoing products. By means of conscious symbols we generalize from individual bits of data, assemble them into patterns, and make abstractions from them by scanning, ordering, and arranging temporal and spatial sequences, and so forth. Throughout life this goes on unceasingly. Relatively speaking, the processes of conscious symbolic sampling are slow and limited, and provide only weighted fragments of preconscious activity, to make up what is erroneously referred to as "conscious thought."

In sleep, preconscious processing constitutes a variable but apparently continuous dream flow. Of this, "the dream," as we ordinarily think of it, is only a condensed fragment, a weighted sample, expressed predominantly through visual imagery—a cluster of visual hieroglyphics with multiple simultaneous implications on all three levels.

Unconscious processes constitute a distorted and even more fragmentary symbolic sample of conscious samples. Note in this connection that it is never the symbolic image, thought, or act which is unconscious, but its relation to that which it is supposed to represent, but masks instead.

It is possible only to outline here this working hypothesis concerning the nature of human mentation. Its implications for the learning process will be considered next.[2]

How we learn. Preconscious learning is both effective and effortless when it operates without interference. It is not easy, however, to attain this. The preconscious stream may be hampered first by the process of conscious sampling. Yet conscious sampling is needed for communicating to others and also to ourselves (that is, ruminating), for creating multiple associative linkages, and for testing the products of the preconscious stream against reality. These are essential ingredients in all mentation and in all learning; but they should not be confused with the acquisition and mastery of new data, nor with thinking, nor with the rearranging of data into new combinations (that is, creative thinking). Furthermore conscious sampling is slow, labored, digital, and literal. Preconscious activity on the other hand is an analogic process and proceeds at a speed far greater than the pedestrian pace of conscious symbolic processes and with greater fluidity. Consequently, even the spontaneous acquisition of symbolic processes which occurs in early childhood slows up and inhibits the child's free play of precon-

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scious creativity. From early years, therefore, the conscious ingredients in the learning process hamper the preconscious processing of data.

When we come to formal education we find that conscious drill and grill constitute a large part of conventional educational techniques. Their premature use in the educational scene increases the hampering influence of conscious processes, jeopardizing, distorting, and inhibiting our processes of preconscious learning, instead of reenforcing, sustaining, and protecting them. Educational research today should attempt to discover how to protect preconscious functions in all education, but especially in education for creativity.[3] Except for isolated pioneers among them, educators have not begun to study this. If engineering educators will turn their attention to this problem and can solve it, they will solve one of the basic problems not merely of engineering education alone but of all education.[4]

The neurotic process in education. There is a further distortion of the educational process by concurrent neurotic processes. This challenges us with the question of whether established educational procedures intensify or lessen the activity of the ubiquitous masked neurotic ingredients in human development. This requires a condensed statement of a working hypothesis concerning the neurotic process.[5]

There is a universal neurotic potential in all men who are not so defective mentally as to be unable to represent inner and outer experience by means of conscious symbols. The capacity to sample the preconscious stream by means of conscious symbols is essential for man's unique psychological activities; yet the process of symbolic sampling is itself vulnerable to two kinds of dissociation. The symbol can be dissociated (a) from the memory traces of the events which it was intended to represent and (b) from the affects which are appropriate to the experience. Such dissociations are the origin of what is known as "repression," that is, the interposition of a barrier between the symbol and its roots. Note that the symbols themselves never become unconscious, but that in the process of dissociation their links to originating experiences and to the associated affects can be distorted or severed. Such dissociations occur under the influence of painful conflicts; and when this occurs it interrupts the associative and symbolic links to the underlying conflicts. In this way the conflicts themselves become "unconscious," and can no longer be dealt with by conscious deliberation, yet con-

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tinue nonetheless to impede and distort both the stream of preconscious activity and its symbolic representation. This is the inception of a continuing neurotic process, because all subsequent thoughts, feelings, and behavior acquire some of the quality of neurotic symptoms and represent the unconscious conflicts. Sooner or later, these symptoms have new destructive secondary effects on the individual's life, which produce new crops of symptoms, which in turn produce tertiary distortions, and so on. Thus the neurotic process consists of a cybernetic or reverberating chain of symptoms which produce distortions which produce fresh symptoms which produce fresh distortions, and so forth.

There is no culture of which we have any knowledge which has solved the problem of how to bring up its children free from neurotic distortions. These may vary, but they are always present to make up the universal masked neurotic components of what we euphemistically call "normal" human psychology.[6] Their influence on all education is destructive, but especially on that education which aims to inform while protecting and preserving potential creativity.

Man's development has always been limited by the fact that his preconscious functions become trapped between, on the one hand, the pedestrian, halting, earth-bound, reality-oriented processes of conscious symbolic representation, and, on the other, the neurotic distortions of symbolic processes which are imposed by unconscious conflicts and their secondary and tertiary consequences. Education itself is caught between the two.

Developmental distortions. If we are to do anything about this problem we must view it ontogenetically, starting perhaps by acknowledging our past culpable indifference to the implications of the child's early loss of free and spontaneous creative zest. The small child manifests his latent and potential creativity in his imaginative use of bodily movement, gestures, facial mimicry, sounds, words, images, color, design, and tone. When he learns to use words, even before formal education starts, he becomes less free, because words themselves confine the preconscious stream. Yet if he is to become educated, the child must master these essential symbolic tools.

If we acknowledge this, we may search out ways to protect our essential preconscious processes from this inhibiting by-product of the equally essential conscious symbolic processes. Instead, we make use of educational procedures which intensify the inhibitory impact of conscious processes, reenforcing at the same time the play

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of neurotogenic influences. The result is that even the highly gifted child suffers a progressive attrition of his potential creativity.[7]

Before formal schooling is begun, the acquisition of symbolic tools occurs, largely through the child's preconscious imitation of others (technically called "identification"). Consequently the quality of the emotional feedback from older people has a powerful influence (either supportive and creative, or else deforming and blocking) on the steps by which symbolic tools are acquired. It is no accident that the neglected child who is starved for the attention of loving adult models is often unable to read or write, even when he has a high IQ.

Even under more favorable circumstances, the process of symbolic learning goes through at least three critical steps in human development, during each of which it again becomes vulnerable: (a) during earliest childhood as already described; (b) in the emotionally charged transition from puberty into early adolescence; and (c) during the long years of higher education, when the student must face the imminent challenges of maturity. Each of these phases of change and growth is charged with hidden rivalries, hates, lusts, and conflicts, many of which are unconscious. The unresolved residues of each critical phase are buried but not eliminated; and in subsequent phases they are expressed in new symptomatic forms, which make use of the recently acquired symbolic tools and processes. This produces further distortions in the symbolic process itself, which is another manifestation of the chain of cybernetic processes by which the neurotogenic distortions of our symbolic tools attach themselves to and ultimately frustrate the learning process.

Again during the upper reaches of higher education—that long-drawn-out period of developmental and educational stress—conflicts arise over accepting the full implications of maturity (intellectual, sexual, economic, marital, parental, professional) with a reactivation of unresolved sources of self-doubt, jealousy, hostility, terror, and so forth. These distortions of symbolic function influence the perception, imprinting, recording, ordering, storing, scanning, and processing of bits of information and their accessibility for use and recall. They influence also the free use of preconscious processes for creative purposes, that is, for taking apart bits of data and putting them together into new combinations. None of these essential processes is isolated from the influence of concurrent unconscious processes. Even our primary perceptions are vulnerable. Therefore,

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the play of hidden neurotic forces can disturb the education of even the most gifted student. It can also defeat, deflect, and distort the creative productivity of highly trained and technically mature scientists of proven gifts. Such neurotogenic defeats occur at every level in the training and utilization of engineering skills, from the first year as a student on through those later years which should be a period of maximum creativity in the life of the mature scientist.

Neurophysiological variables. Also influencing and sometimes distorting the learning process are variables which depend upon neurophysiological idiosyncrasies of the human central nervous system. Among these are the conflict between the storing and preconscious processing of data, the effects of input-overload on preconscious creativity, the effects of the lengthening span of student life on the retarding of emotional maturity, and the effects of this aspect of the life of the engineering student on his freedom to grow, to create, and to produce.

I have already touched on the fact that, in all educational settings, rivalry plays a role in the activation of latent neurotogenic processes. Such rivalry can also be intensified by the excessive and premature emphasis on drill and grill, based as it is on a fallacious assumption concerning the role of conscious processes in learning. Destructive rivalries can also be intensified by the injudicious and over-enthusiastic use of testing procedures. The effects of these and other conventional "educational" techniques should be subjected to comparative studies, specifically with regard to their interaction with neurotogenic processes.[8]

The consequences of universal, concealed, neurotic processes for the education of engineers and for their subsequent creative productivity are matters of urgent concern. This is not because there is any evidence that engineering education is more vulnerable than education in other fields; but rather because science is the most basic discipline among the humanities. Therefore the illumination of this problem in engineering would throw light on its significance in less precise fields of education and therefore on the educational process in general. It is of further importance to solve this in engineering because of the high cost of engineering education and its practical importance.

II. *The Problem at the Student Level*

Departmental heads and administrative officers from various in-

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stitutes in the engineering sciences emphasize the fact that students and faculty as well are carefully screened, both before coming to them and continuously thereafter as the progress of screening moves through a progressively finer mesh. All agree (and on this their testimony is remarkably consistent) that wide discrepancies between earlier records and later performances are frequent, and that these discrepancies occur among undergraduate students, graduate students, research fellows, and the faculty as well. There is further agreement that because of the frequency of these discrepancies the productivity of the group as a whole is far below that which one could justifiably expect from such concentrations of outstanding talent.

Recently the dean of a major school of engineering said that he had become convinced of several things: that of this selected student body not more than five to ten per cent become creatively productive; that there are some who demonstrate a high absorptive capacity, but never produce ideas of their own; that there is little correlation between creativity and high marks, or even between creativity and the mere fact of survival through the engineering course; that forty to sixty per cent of all students leave because of failure or else drop out voluntarily in spite of passing grades, and that together these two categories of "drop-outs" include a major share of those with high potential creativity; and that our educational processes tend to destroy the creative potential of a large share of those who survive.

My own observations in other educational fields point to similar generalizations. Yet I cannot pretend that I have conclusive evidence for the truth of this; nor has my friend, nor anyone else. For many reasons, however, I believe that it is possible to study this problem with special precision in engineering, and that a solution here would contribute to its solution in general.

Many scientific schools emphasize also that the later productivity of their faculties cannot be predicted reliably on the basis of their earlier effectiveness in graduate school or in previous academic posts. Thus, even in the upper echelons, men of high initial "yield" may grind slowly to a stop and become unproductive. There would seem to be some "X" factor in education which plays an important role and which we have not yet learned to recognize or to measure.

The converse of all of this also occurs with a frequency which is still less clearly determined. Some men of little early promise become unexpectedly fecund. Among students at all levels are men

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whose performances on examinations had been low but who prove in the end to be creative. Some illustrious scientists failed examinations repeatedly (for example, Pasteur). Still others performed either up to or down to the expectations which their early tests and performances had aroused. Finally there are the irregular profiles of men whose performances at different stages of their lives and in different yet related fields revealed wide discrepancies.

Some experienced scientific and engineering educators believe that their educational processes and their students are especially vulnerable. Although scientific education is not exempt, these pessimistic impressions are not the outcome either of precise studies of engineering education or of comparative studies of the nature, the extent, the quality, and the quantity of the discrepancies which occur in these and other disciplines. If such studies are to be carried out, samples should be assembled for study by new and special methods.

A few examples of the consequences of neglecting these problems may make their importance clear.[9] There are students who perform and even produce brilliantly but only up to the point of graduation (or of receiving advanced degrees). There are the flash-in-the-pan investigators who turn out one or two creative jobs early in their careers, but thereafter become so paralyzed by inner conflicts that they never produce again. There are others who seem to acquire creative freedom only slowly and relatively late in life, as they gather the courage which is needed for that free use of preconscious processing on which creativity depends.[10] From earlier studies it appears to be true in general that this freedom must wait upon the resolution of pre-existing conflicts, which may have manifested themselves only in seemingly unrelated symptoms.[11] There are those who are highly successful and productive for many years, but who become increasingly despondent and dissatisfied in spite of success. There are others who remain relatively unproductive, yet seem content almost to the point of complacency. Some young scientists will cease being productive after marriage. For others, precisely the reverse occurs. There are men whose productivity is intermittent, and who go through long periods in which they are totally barren. Sometimes these prove to be enriching years of lying fallow. For others these are catastrophic years, from which their creative talents never recover. For Mark Twain, one such period lasted for ten desperate and nearly suicidal years before he could finish *Huckleberry Finn*.[12] For Beethoven, this occurred repeatedly

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with the waxing and waning of his psychopathy.[13] The scientist and the student of science are not immune to processes to which their creative counterparts in these other fields are vulnerable.

Related to these blocked periods is the drive of those who are slaves to an insatiable need, sometimes spoken of euphemistically as a "hunger for knowledge." Subjectively it is more often felt as a tense, irritable, angry, restless discontent; and its unconscious roots make it as compulsive as compulsive eating (which has its roots not in the body's recurring need for food, but in an array of unconscious processes). The same neurotic distortion of normal curiosity can distort the search for knowledge and for the mastery of any field. In considering this surprising analogy, it is important to remember the clinically well-known fact that compulsive eating can turn suddenly into a total refusal of food. In a precisely similar way, when the drive for knowledge has major roots in unconscious symbolic processes, an insatiable "hunger" can turn almost overnight into an equally obstinate rejection of knowledge and an inhibition of learning and indeed of intellectual activity of every kind. Unhappily such reversals from voracious learning to rejection occur frequently and at any age. This has been happening for centuries under the eyes of educators; yet no serious investigation has been made of its roots, causes, or precise frequency.

Instead the driven student or scientist who becomes blocked is usually assailed by epithets such as "recalcitrant" and "lazy," because the neurotogenic nature of his reaction is generally overlooked. This is one of the elementary neurotic distortions of creative learning; and because every intergrade occurs between the extreme poles of compulsive over-drive and phobic inhibition, a study of the pathological extremes will throw light on the "normal" shades of gray. The whole range of the spectrum is a necessary field for fruitful investigation.

The entire course of a student's productive life may be determined by the age at which there is a change from over-drive to inhibition or, in the reverse direction, from inhibition to release and even to over-drive. A shift in either direction may occur upon changing from one classroom to another, from one teacher to another, from one school to another. It may happen the first time a youngster goes either to a mono-educational or to a co-educational school; or the first time he goes away from home to school or college. I have seen one youngster drop from top to bottom of his class and another leap from the bottom to the top on being sent away to a

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boys' preparatory school—in one such instance away from the aura of a brilliant and favored sister.

Another example is the depression which may account for sudden slumps, yet may go unrecognized from kindergarten to the highest reaches of postgraduate training. Many who seem to be day-dreaming are actually in masked depressions. Release from such paralyzing depressions can occur with equal suddenness, and with a dramatic but transitory increase in the effective use of latent creative capacity. The frequency of these changes during the period of engineering education or later, and how often they remain unrecognized for years are important facts to determine. If a slump occurs early and lasts for several months it may block a gifted youngster's whole further career and development. Not only can the experience be so painful that he may never be able to return to the study of science, or indeed anything else; but it can also close all academic doors to him. When it happens at a critical phase in a young scientist's career, it may hamper his entire lifework. When it occurs later in the career of a man who has already achieved tenure, the consequences will be different and less dramatic, but no less serious. Such a scientist may save himself from feelings of defeat by devoting himself to teaching, to administrative positions, to useful service to foundations, or to college presidencies. This in turn creates its own chain reaction of consequences for our educational and research institutions and foundations. Is it for this reason that even leading educators find excuses for not investigating these problems? Do they come too close to some of us for comfort? Yet since all productive and creative people and their activities are vulnerable to neurotogenic distortions, the problem is of general significance. Any investigation of this problem would set out to ascertain how and when such transformations of a normal work drive into compulsive over-drive occur; and how often an obsessional work block is the delayed aftermath of such compulsive work drives. Tracing the natural history of the process would include a study of how these changes were interrelated with disturbances in other fields of interest and activity, both instinctual and general.

Another form of neurotogenic distortion is equally familiar. It concerns the promptness with which work is done. There is the man whose anxieties compel him always to rush, always to be ahead of time. This is the man who gets to every train not only on time but early, the student or investigator or lecturer whose work is always done long before it is necessary. In his hurry such a man can rarely

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stop to think, to read, to digest, to lie fallow. His opposite number gets to the train only as it is pulling out of the station. He is the student who barely gets his themes in on time or consistently brings them in late. He can never think about a problem (much less work on it) until he is under last-minute pressure. Therefore although he can sleep and daydream, he cannot lie fallow either. Thus neither the compulsive rusher nor the obsessional dawdler can allow his associative processes to drift creatively and freely. What chance then has either for that play of free-wheeling preconscious processing which is indispensable for creative activity of any kind? Again these patterns of compulsive rushing and obsessional dawdling are observable from the kindergarten throughout the graduate years. At the start they are equally neurotogenic in origin; but the dawdler is penalized from the onset, whereas in his early years the rusher is rewarded for his neurosis. It is only later that the tax collector catches up with him. Thus at every stage these differences can exercise a distorting influence on all processes of study, of perceiving, recording, and reporting experiences and observation, of imaginative rumination, and of creative experimentation.

The challenge of prediction is another variable which adds its dimensions to the problem. All scientific hypotheses and experiments carry the implication of a prediction. Yet scientists vary in the courage with which they are willing to venture to commit themselves by making explicit the predictions which are always implicit in their work. To venture a prediction is to expose oneself in a special way to being proven right or wrong. Predictions which remain unspoken leave us safely under cover. In our lurking fantasies this can have many highly charged implications. There is an important difference in the neurotic forces concealed in the scientist who ventures to make his predictions openly and the scientist who hides them. (Predictions also challenge us to develop some way of scoring certain critical ratios: (a) the ratio of implicit to explicit predictions in general and (b) the ratio of correct to incorrect predictions among both implicit and explicit predictions.)

There are many other revealing clues to pursue. The emotional implications to a man of his own scientific work may be betrayed by an inability to lie fallow without anxiety, either after successful work or during the frustrating interludes of inhibited struggle. The ability to work effectively both alone and in collaboration with others is another indicator of the extent to which creative processes are relatively free of interference from neurotic distortion and con-

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trol. Indirect reflections of these traits may be found in the quality of the scientist's relationships to his own family and to his students and colleagues during various phases of his work.

Even a preliminary survey would bring to light other clusters of working traits, which subsequently could be used in the classification of data into relevant subgroups. These examples are only a few of the many neurotic patterns which one would expect to encounter in studies of the working patterns of established scientists and students of science, and in comparisons of representative samples from contrasting groups.

There are neurophysiological variables as well which influence the learning process and are interwoven with the effects of neurotogenic processes. However, only limited gains in education can be attained by improvements which are made solely in neurophysiological techniques and procedures; the neurotic process, which is universal, must simultaneously be brought under some measure of control and resolution. For instance, there is evidence that anomalies in the organization of the connections between certain areas in the brain can cause reading, writing, spelling, and calculating difficulties, which are due in part to reversal of the spatial sequence of visual and kinesthetic bits of information, and perhaps temporal reversals of auditory data as well. Thus "saw" may be read as "was." Or there may be a confusing superimposition or alternation of reversed sequences or images. This was demonstrated by the late Dr. Samuel T. Orton,[14] who called it "Strephosymbolia" and developed ingenious methods for training students who were handicapped in this way, even though in all other respects they might be exceptionally bright. It became clear to him that the effectiveness of these special techniques was limited unless steps were taken simultaneously to bring psychotherapy to bear on the concurrent affective and neurotic problems of the student.

Other studies of educational processes have shown that it is only at the upper and lower extremes of the normal curve of distribution that the IQ and special aptitudes play a dominant role in determining scholastic and creative achievement. For the so-called "bright normal" students, who make up the vast majority, limits are set rather by the play of concealed neurotic processes. The Air Force studies of "Stanine" scores demonstrated the same fact.[15]

III. *The Problem at the Graduate and Faculty Level*

Operational concepts about productivity. Any attempt to foster

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productivity implies an ability to recognize latent productive talent, variations in its quality and quantity and also in its freedom to emerge as manifest creative productivity, plus qualitative and quantitative variations in the products in which it is expressed. None of this is easy; but it is not impossible.

The mere volume of a man's output is not a sure measure of his scientific "product," whether the number of investigations, of published and unpublished papers, or of honors is used as the measure. The product must also meet standards of quality which can be almost as arbitrary and ephemeral as are fashions in gowns. Fashions play a role in science as in all human pursuits; and these sometimes inflate or deflate reputations without regard to ultimate values. Furthermore the game is never over until the final score is in, which may at times take years of waiting.

How, for instance, can we estimate the relative productivity of these men? One spends twenty-five years in obscure and often defeated struggles before finally breaking through into a new frontier. Another spends the same twenty-five years publishing at least one report each year on definitive but limited investigations, some with positive and some with negative results. For the investigator who is addicted to counting, the second man has been the more productive. But this does not necessarily make his stature either greater or smaller than that of the worker who waited for twenty-five years, and whose one final discovery may furnish many others with a lifetime of problems to explore, techniques to use, and principles and theories to test. Still another may turn out skillful, erudite, and precise yearly experiments which yielded negative results, which prove only that some hypothesis has been wrong. This may not have been directly productive of new knowledge; but it may have cleared the way for another's breakthrough. Indeed without the dedicated labors of countless obscure men who proved only that certain clues had been misleading, many winners of Nobel prizes would have missed their objectives. Even great scientific intelligence and imagination may fail at any particular period in the evolution of science, because of the lack of specific scientific techniques or theory at that time. Therefore the erudition, imagination, skill, and devotion of the man who corrects the errors of others, or who doggedly and skillfully pursues false clues into their ultimate blind alleys, may be as great as that of a man who uncovers a new fact or principle. These are the unknown and unrewarded heroes of science, its many "expendables." They are no less essential than are the few who reach

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their goals. Indeed one of the unique honors of science is the humility and honesty with which it constantly struggles to correct its own errors. It is this which makes science great among the humanities. This also is why the autopsy table is one of the proud events of human culture.[16] Our thinking about the education of the scientist must include the less spectacular but equally vital achievements of those who disprove the false.

There is also the man who says of himself that he always loses his way in experimental work. By his own statement, such a man was the late Dr. W. H. Welch.[17] Yet his critical judgment was so acute and informed that he guided the work and the development of a whole group of younger associates.

For such reasons as these, even after many years had passed it would still be hard to say which of these men had had the greater impact on scientific knowledge. Consequently potential productivity cannot be measured only by immediate or deferred positive achievements. Neither will give us a rounded understanding of the creative process in science, nor in the long run improve our methods of choosing men or of nurturing their talents.

An initial problem then is how to recognize and estimate relative degrees of productivity in its several forms: (a) among the quick and immediate "producers"; (b) among those whose work bears fruit only slowly and less predictably; (c) among those many students (and faculty) who fail to achieve spectacular positive results, but who make their contributions by the definitive precision and even the brilliance of the "failures" by which they disprove errors; and (d) finally among those highly gifted thinkers and critics who do little or no work themselves, but who inspire and guide the productive careers of many others.

Thus there seem to be at least four kinds or qualities of useful scientific productivity. Actually there are even more, and one may find all of them in the lifework of one man either at the same time or in different phases of his career. In these differences and in their fluctuations during any one man's life, both healthy and neurotic forces exercise concurrent determining influences and will determine the freedom with which a man will use his latent gifts.

A mature program of scientific education would take all of this into consideration, and also what it means emotionally to the student or to the mature scientist to be one of the "expendables," instead of one of those who triumph. With this in mind the education of scientists should include measures for maturing and strengthen-

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ing them, so that disappointments will not embitter or destroy. This is not solely for humanitarian reasons. It is also for the sake of scientific progress as a whole. The thinking of the scientist who is embittered becomes distorted and feeds fresh distortions back into his own further creative efforts and into his influence on his students and their work. Thus one man's bitterness can produce distortions which may propagate themselves in future scientific generations.

Creativity: operational concepts and research. We must attempt to characterize more precisely not only the process which leads to a manifest creative act, but also what is implied by latent creative potential. Operational concepts about this are still tentative; and even if our characterization of such a potential is reasonably accurate, we may not yet be able to assign to it specific quantity values. We may have to content ourselves with the simpler judgment of "present" or "absent."

The uncovering of new relationships among both new and old data is not the whole of creativity; but it is what the creative process adds to the mastery of established data.[18] Thus creativity implies invention: the development of new machines or processes by placing old facts and principles in new combinations, and then uncovering through them still newer facts in new combinations, thus synthesizing new patterns out of data whose interdependence and mutual relevance had hitherto gone unnoted and unused. This requires both "Cogitation and Intelligence":[19] that is, "Cogito"—shaking things up, rolling the bones of one's ideas, memories, and feelings, taking them apart into bits to make new combinations; plus the superimposed process of "Intelligo"—consciously, self-critically but retrospectively going through an after-the-act process of choosing from among unanticipated combinations those patterns which have new significance. It is the sum of these steps which constitutes creative activity. The critical psychological event is the recognition of new data and new relationships, their dissection into new bits, the assembly of these bits in new combinations, giving rise to new facts and principles.

These, however, are all *preconscious* processes, not the outcome of either conscious or unconscious processes, as has been claimed mistakenly both before Freud and since. Therefore, what we must learn to assay is the potential freedom of preconscious processes to operate relatively unhampered by concurrent conscious or unconscious co-determinants. In essence, this is identical with the ability to identify relative freedom from neurosis, an equally elusive task.

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Conscious processes deal only with the finished product of creative preconscious thinking. They sample the stream of preconscious activity in a somewhat pedestrian fashion, and then check and test the sample, anchor it to reality, and communicate about it to others and also to one's self in rumination. If introduced prematurely, they confine, limit, slow up, and restrict the play of preconscious processing. The influence of unconscious process is both to distort and to render rigidly repetitive the sampling of the preconscious stream by our conscious symbolic process thus limiting the free creative preconscious flow. An inquiry into the influence of any educational procedure on the creative potential of men should study the impact of the two concurrent processes, conscious and unconscious, on the preconscious imprinting of percepts and on the free play of preconscious processing.

Even before formal education starts, the small child begins to lose his spontaneous creative freedom as he acquires the power to sample the preconscious stream by means of conscious symbolic devices. This imprisonment of preconscious processing occurs precisely because the process of conscious sampling, essential though it is, is both slow and literal, making little or no use of analogic relationships. At this point our problem is to understand how the later imposition of conventional educational methods increases this imprisonment and how to educate for freedom in the future. Such a study will confront us with the technical problem of how to estimate the degrees and areas of freedom of preconscious processes, as these operate between the pedestrian, literal, reality-anchored restrictions of our conscious sampling processes, on the one hand, and the rigid, repetitive, stereotyped, neurotogenic limitations imposed by unconscious processes on the other. Since the degree of preconscious freedom determines the latent creative potential, methods are needed by which to assay the extent to which conscious and unconscious processes are hampering potentially creative preconscious processes. A study of this would illuminate the interaction of educational processes with the ubiquitous masked neurotic process in the so-called "normal." It should also lead us to an understanding of how to protect the freedom of creative preconscious processes in education while preserving the equally essential processes of conscious sampling, ruminating, and communicating.[20] Educators must first become aware that this problem exists, and that the educational procedures which have been handed down to us over the generations tend to increase the distortions and in-

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hibitions which conscious and unconscious processes exert on preconscious creativity. We will make progress here only as educators come to realize the importance of better methods for the development of creative freedom in the student of science, in the mature scientist in his later years, and in all of the humanities.

IV. *The Development of Pragmatic Criteria for the Prediction of Effective Creative Productivity*

The gradual validation of criteria of creative productivity requires that precise data on earlier tests and records be correlated with the same individual's later productivity. On the student level and in successive steps of scientific schooling, familiar items would be grades in lower schools, on admission examinations and in advanced schooling. Less easy to secure would be dependable information on promptness or delay in the completion of tasks and problems —whether there has been an early history of compulsive rushing, haste, and general over-drive or of obsessional dawdling, daydreaming, and ruminating. Of special importance would be a complete history of any changes in such patterns, including when such changes occurred and whether they had occurred suddenly or gradually over years, as well as an account of alterations in the external life-setting and internal adjustments which led up to these changes. Much of this highly personal data could be obtained only through meticulous investigation of individuals selected as samples out of various basic groups.

Reports on the quantity and quality of independent creative work during advanced schooling would also be essential but more difficult to secure. Qualitative estimates of "originality" or "newness" would require subjective judgments of individuals about themselves to compare with the judgments of their teachers, of their peers in their respective fields, and of men of equivalent stature from other but related fields.

Descriptions of habitual patterns with respect to the use of leisure and particularly of the capacity to lie fallow without panic would be helpful, as would data on the sensitive balance between the freedom to change methods or fields of research as opposed to the ability to keep on without swerving in the face of disappointments.

Collecting such information is never easy or free from the influ-

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ence of many hidden biases, of which the informants themselves are usually unaware. Therefore the evaluation of reports on these issues, whether from the individual subject or from other informants, would require the use of several investigators in order to balance the bias of any one.

A composite scoring system for so many variables is difficult but not impossible; and it is less difficult for undergraduate students than for graduate students and faculty because records of the productive performance during the three or four undergraduate years are more readily accessible.

A greater difficulty arises when any effort is made to extrapolate from the past into the future: that is, from the capacity to perform competently as an undergraduate student to the ability to create independently as a graduate student, and finally to the ultimate capacity to be creative as a self-starting and self-steering, mature, and independent scientist. Criteria for this can be developed only by placing faculty members and productive scientists in contrasting groups on the basis of their capacity for creative originality, using self-scoring and cross-scoring devices, as well as their self-image. Yet these could not serve alone as objective data. Only a few mature scientists would be able to score accurately the extent to which their creative productivity had fallen short of or exceeded their earlier expectations. Some would score themselves too low and some too high, for obscure inner needs can frequently warp self-scoring in either direction. Therefore it would be essential to determine whose self-scores are objectively accurate, whose are self-inflating, and whose self-deflating.

Another group of criteria involves such items as the ability to predict within reasonable limits how long a certain piece of research will take, and its cost in money, materials, space, and assistants. Such earthy considerations are measures of the extent to which reality molds the setting and pace of the creative effort, as contrasted with the extent to which neurotogenic processes distort it to serve secret needs.

Variations in the relative distribution of time between the production of positive creative work as compared to the amount of time devoted to corrective research would give important leads to differences in the emotional significance of all research. One type of investigator always sets out to prove that earlier work was wrong, whether his own or that of others. Another type attempts to show that he has always been right and others wrong, or that he was al-

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ways wrong and others right, or that all were right. An exclusive emphasis on research which produces negative results, however significant these may be, furnishes a clue to unrecognized and therefore unacknowledged emotional biases.

It is relevant to point out that during the educational process itself, such group studies as these can also have therapeutic effects, for example, by developing a student's capacity for self-criticism and for evaluating his own attitudes toward people as expressed through his work. He may even come to recognize the point at which healthy criticism becomes overdriven and destructive, whether of himself or of others, until it finally becomes an excuse for producing or finishing nothing. I can think of three scientists of high potential in three different fields who misspent their lives creating nothing because obsessional-compulsive mechanisms took over the intrinsically useful function of criticism. They did *nothing* but criticize—today themselves, tomorrow others. The seesaw never ceased. In estimating the creative potential of any man, these considerations would have to be compared with the amount of definitive creative research which provided new data or new relationships or established new working hypotheses.

Another comparative study would be of the ratio between the amount of time spent acquiring and mastering new material, the amount of time spent in systematic trial and error, and the amount spent in lonely, desultory rumination. At one pole one thinks of the late L. J. Henderson spending weeks away from his laboratory, ruminating, dreaming, and "free-wheeling," then going to his laboratory for one short, intensive bout of research. At the other pole one thinks of the compulsive worker who must always live in a continuous flurry, rushing through the motions of trial and error every day from early to late. Or one thinks of Poincaré, Otto Loewe, and many others who did their creative thinking in states of abstraction, of sleep, and even of dreaming.

The ultimate goal is the mind well-stocked with matured data, that acquires erudition without becoming leaden, that can carry its erudition lightly, freely, imaginatively. But to define this goal is one thing; to recognize and assay its presence is another; to evaluate the influence of our educational procedures a third. We know that there are no easy formulas. For instance a concurrent grasp of the non-scientific humanities sometimes goes hand in hand with this preconscious freedom; but the pursuit of the humanities does not produce this automatically. Many scholars of the humanities are as

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inflexible as scientists. Here as in the sciences themselves it is the creative freedom of the pursuit which counts.

V. *Procedural, Organizational, and Financial Considerations*

In designing a project to investigate the effects of education on scientific creativity, it would be necessary to start by identifying several major groups of students and mature scientists: (a) those of high initial promise whose later performances fulfill the early promise; (b) those of low initial promise whose later achievements are what had been expected; (c) those of high early promise who fall far below this; (d) those of low initial promise who exceed all expectations; (e) those who perform well, whatever their earlier promise had been, yet drop out and disappear from the engineering field; and (f) those of low or of high earlier promise whose later performance is not consistently high or low, but scattered and irregular.

The homogeneity or heterogeneity of each of these groups could not be assumed until adequate representative sub-samples had been subjected to intensive individual, cultural, psychosocial, psychological, psychophysiological, and psychoanalytic investigation.

In addition to individual variables, the effects of school variables would have to be taken into account, that is, differences in educational policies and techniques, differences in the methods and standards which govern both the admission to each school and appointments to faculty posts or to research fellowships. These would determine the range and quality of the population which is to be studied and the general level of their performance, which in turn would create the general atmosphere of expectation and pressure. Such studies would have to be paralleled by special tests carried out by a research team, which would venture predictions about the probable degrees and kinds of future creative productivity of all new undergraduate and graduate students and new faculty appointments as well, basing the predictions on appropriate ratings of past performance, special tests, personality studies, and so forth. These predictions would then have to be coded and filed away unused for many years, before significant comparisons could be made with subsequent performances. Pooled data could then be published; but no data on any individual would be revealed. By its very nature, such a study is a long one. It will have to cover more than one generation of students, research fellows, and faculty,

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following them through at least two decades. Moreover no one school can represent all.

Because of the need for comparative data on different schools with different techniques and different student bodies, and because of the highly personal nature of much of the information which must be gathered and the vital importance of protecting the anonymity of everyone, a group of schools will have to create an independent inter-school agency specifically for this purpose.[21]

Therefore, as a first step a group of leaders from several scientific schools, with the help of educators, behavioral scientists, and psychiatrists, would formulate a program of studies to be carried out over a period of years by an independent agency for research on engineering and scientific education.

Such a program of investigation would appeal only to those who realize that in every age and in every human culture of which we have any knowledge, something has been lacking in the processes of education,[22] and that as the span of the years of education becomes longer and as we attempt to educate more people, the price we pay for our educational errors increases.

An approximate estimate of the costs of such a project would seem to be indicated. Let us assume that a study of several representative schools would require about five teams of four each, or twenty specialists detached from their usual duties: five analytically experienced psychiatrists, five clinical psychologists, five psychiatric social workers, and five engineering educators. Their annual salary budget would be in the neighborhood of $400,000. Twenty secretaries at $5,000 would come to $100,000. Secretarial space and equipment, recording apparatus, cameras, lights, studios, and travel expenses are hard to estimate. The total cost per year might range from $600,000 to $750,000. If the study continued for a period of fifteen to twenty years, the over-all cost would be between fifteen and twenty million, including publication costs.

This is a great deal of money; yet it is estimated that the cost of educating each engineering student ranges in different schools from $25,000 to $50,000. It is estimated that voluntary drop-outs, failures, and breakdowns account for the loss of ten to fifteen per cent of all engineering students during their years of training. In addition, there is a large group who graduate but never practice engineering or who leave the profession later. These two groups represent an annual loss to engineering education of not less than one million dollars. Twenty million dollars in twenty years more

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than balances the estimated cost of this study; and if the application of lessons learned in the study should cut these losses at all, the study would more than pay for itself and quickly. Perhaps it would not be too expensive an undertaking after all.

To pretend that a quick and inexpensive study could be made by one or two behavioral scientists would be dishonest and deceptive. An understanding of the reasons for the failures of education in all fields and over the centuries cannot be bought at bargain rates.

VI. *Summary*

Learning, thinking, and creating are predominantly preconscious rather than conscious processes, and when left unhampered preconscious processes are effortless and effective. Yet they require translation into the language of conscious symbols in order to become usable. In one respect this process resembles the effort to translate one's thoughts into a foreign language—it slows down preconscious processes to a labored walk. The struggle between the two begins in earliest childhood as the child learns to speak, and continues through the highest reaches of education. Furthermore, our conscious symbolic tools, which are essential for the learning process and indispensable for man's highest creative functions, are peculiarly vulnerable to neurotogenic distortions. This is a second battleground.

Consequently we have to face the fact that from childhood through adolescence and on into postgraduate levels, education has to overcome two obstacles: the impact of conscious sampling on preconscious processes, and the distortions due to the neurotic process. These two struggles have always haunted human education. Only recently, however, have we begun to recognize their importance; and even today few realize that certain educational procedures tend to activate and intensify these struggles.

Many engineering educators assume that this is peculiar to engineering education, or else that it plays a larger and more destructive role in engineering than in other disciplines. Yet no conclusive evidence for this exists. Careful comparative studies of different disciplines will be of value for many reasons; but the question of whether these obstacles are more destructive in engineering education than in other disciplines is of less importance than is the mere fact that they exist, that they have been overlooked,

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and that they exert a generally obstructive effect on the whole process of education. If any discipline succeeds in resolving these age-old conflicts between conscious and preconscious processes and between neurosis and education, it will open the door to their solution in all.

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LOREN EISELEY

Darwin, Coleridge, and the Theory of Unconscious Creation

TWO GREAT geniuses of the nineteenth century, two men from widely distinct social worlds, yet of strangely similar cast of intelligence, have, by the vicissitudes of fortune, become posthumously involved in a stormy controversy among twentieth-century biologists. One was the poet, Samuel Taylor Coleridge, opium addict, creator of *The Rime of the Ancient Mariner* and the weird moonlit fragment *Christabel*. "For over a century," writes the critic Max Schulz, "the tradition has been that they [Coleridge's poems] defy analysis because the best of them are enchanted records of unearthly realms peopled by Mongol warriors, old navigators, albatrosses, and Lamia witchwomen. . . ."[1] Students of the subject have been until recently loth to perceive the conscious craftsman behind the dreamer. The tendency has been to accept "the sacred river," the sunless sea of dream as the primary source of Coleridge's inspiration. Out of these misty depths, according to entranced critics, were drawn in poetic ecstasy fragments of travelers' tales transmuted forever in the subconscious mind of the poet. The public appeal of this romantic interpretation of great poetry is tremendous. It flatters our imagination and our conception of the mysterious life of the literary artist.

The other man, Charles Darwin, the equally noted discoverer of natural selection, has at first glance a different and scientific appearance. Yet his mind, too, was stuffed with the multitudinous lore of both incredibly wide reading and personal oceanic experience. He openly proclaimed himself a millionaire of odd and curious little facts. There floated in his vast memory the tortoises and lizards of islands under tropic suns. He had dug for fossil bones in Patagonia, and climbed Andean peaks in solitude. Navigators and

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albatrosses were part also of his experience. He, like Coleridge, had read insatiably.

But in his case the public imagination was, and is still, caught by the symbol of a great voyage, the voyage of the *Beagle*. After Darwin's book, *The Origin of Species,* was published in 1859 he wrote to the Reverend Baden Powell, "If I have taken anything from you, I assure you it has been unconsciously."[2] This was in response to a letter in which Powell had reproved Darwin for not referring to one of his works. Thus the legend of the unconscious, the role of the "sacred river," was destined to leave the realm of poetry and enter the field of science. The floating fragments from Darwin's sacred river need no longer be assigned place, name, or priority. They had become the property of genius, they had entered the dark domain of demonic creation. As it is in literature, where historic footnotes are not demanded of the poet, so now it was about to become in science. Charles Darwin was to be elevated beyond giving an account of even partial priority as that rule applied to other men.

Darwin's own excuse of the "unconscious" has been increasingly used in recent years by defenders of the great biologist in considering the problem of Darwin's meager attention to his predecessors. If Darwin "unconsciously" borrowed material without acknowledgment, some scholars imply that no blame can be attributed to him. Rather, they frown upon those historians of science who persist in probing beneath the insights of genius in order to seek the sources of their inspiration. Yet we must still ask, was the one man who should know where he got the idea of his famous theory unconscious of where he got it? Or did he consciously draw a veil over one predecessor in particular, rationalizing, perhaps, as he is known to have done on one occasion, when he implied that the man who successfully convinces the public of a new idea deserves all the credit which may accrue to him.[3]

The theory of the "unconscious" has been emphasized by Darwinian defenders particularly following the publication in 1959, in the *Proceedings of the American Philosophical Society,* of an article which explored the possible role played by Edward Blyth, a young British naturalist, in the formulation of the theory of natural selection.[4]

We now know that Blyth stated the basic tenets of the theory of natural selection in two articles in *The Magazine of Natural History* in the years 1835 and 1837.[5] We know also that Darwin footnoted Blyth copiously in his books on many subjects, but never on natural selection, although it is clear from the nature of his reading and in-

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terior evidence from his notebooks and early essays, as well as one letter, that he was familiar with the magazine containing these important articles. The recent publication of *Darwin's Notebooks on Transmutation of Species*,[6] in 1960, showed clearly that Darwin was aware of Blyth's writings on natural selection. In the *Second Notebook*,[7] never intended for publication, reference is made to the article of 1837 in which Blyth writes, after having earlier in 1835 described the conservative effects of natural selection: "May not, then, a large proportion of what are considered species have descended from a common parentage?"[8]

Several who are unwilling to credit Blyth with influencing Darwin refuse to quote this line of 1837—the very year that Darwin conceived of the role of natural selection in evolution. Sir Gavin de Beer, who edited the Notebooks, footnotes Blyth's article as mentioned by Darwin in the *Second Notebook*, but fails to point out its obvious import. In a brief discussion of Blyth in the Introduction to the *First Notebook* he at first remarks that Darwin probably owed nothing to Blyth so far as the construction of his theory is concerned.[9] He confesses, however, in the same paragraph, that "there is nothing improbable in his [Darwin's] having copied some from Blyth." He then cautiously concedes that "Darwin (and others) may have been wrong in thinking that he owed him [Blyth] or them nothing on this score." Four years later, in 1964, in his biography of Darwin, de Beer has again retreated from a direct confrontation of the full nature of Blyth's speculations when he says that although Blyth "had been playing with the very tools that Darwin so successfully used, it is difficult to see that Darwin was indebted to him, for his conclusions were the exact negation of what Darwin was trying to prove."[10] Concerning this statement it is of interest to note that George Wald, writing on "Innovation in Biology," in the *Scientific American*, remarks that "all great ideas come in pairs, the one the negation of the other, and both containing elements of truth."[11] Edward Blyth, as we have seen, in a moment of insight glimpsed momentarily both faces of Natural Selection. It was enough to give an astute mind like Darwin's the clue that he was seeking. Today it is well recognized that this principle is composed of both creative and conservative aspects. In nature, natural selection maintains the species as well as promoting slow and tested change at the same time.

Theodosius Dobzhansky, who uses the "unconscious" theory to explain Darwin's failure to acknowledge his predecessors, accepts the fact that "the fundamental premises of the theory of natural selection

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are contained in Blyth's essays,"[12] but maintains that Darwin might have been mistaken about the sources of some of his ideas, and his thinking process might not have been wholly free of subconscious components.[13] Dobzhansky's theory of the "subconscious components" as the probable cause of Darwin's omission of credit to Edward Blyth should be considered carefully because it gives us an opportunity to explore one interpretation of the creative processes of genius.[14]

"Is the origin of every idea which crosses our minds always clear to us?"[15] Dobzhansky asks. Nobody, he contends, has a perfect memory and is always aware of his thinking processes.

> Probably everyone is familiar with the feeling that an idea which arises in one's mind, or a phrase which emerges from one's pen, have been met with somewhere, but one cannot recall just where or when. This feeling is sometimes justified but perhaps more often illusory. Might not even Darwin have been mistaken about the sources of some of his ideas?[16]

It is the mystery of the creative process in the mind of genius which the discovery of Edward Blyth forces us to face, argues Dobzhansky. In Darwin's defense, Dobzhansky cites John Livingston Lowes' well-known study of Coleridge, *The Road to Xanadu*. Dobzhansky feels, as did Lowes, that "it is not illegitimate to compare the creative processes of a poet, Coleridge, with those of a scientist, Darwin."[17] Since the creative work of a poet and of a scientist are not fundamentally different,[18] Dobzhansky maintains that Darwin had little more awareness of the soil in which his theories grew than did Coleridge of the sources of his poetry. Unfortunately for Dobzhansky's reliance upon Lowes' interpretation of Coleridge, however, later critics no longer see the great romantic poet as purely an inspired somnambulist. In the first volume of Kathleen Coburn's edition of Coleridge's notebooks, says Schulz, "the notations of ideas and images for future poems recorded in them reveal a mind knowing where it is going and moving purposefully toward that goal."[19]

Could Darwin have been unaware of the fact that he had read and utilized the articles written by Edward Blyth on the subject which he was later to claim completely as his own discovery? Lowes has written:

> The "deep well of unconscious cerebration" underlies your consciousness and mine, but in the case of genius its waters are possessed of a peculiar potency. Images and impressions converge and blend even in the sleepy drench of our forgetful pools. But the inscrutable energy of genius which we call creative owes its secret virtue at least in part to the enhanced and

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almost incredible facility with which in the wonder-working depths of the unconscious the fragments which sink incessantly below the surface fuse and assimilate and coalesce. The depths are peopled to start out with (and this is fundamental) by conscious intellectual activity, keyed, it may be, as in Coleridge's intense and exigent reading, to the highest pitch. Moreover (and this crucially important consideration will occupy us in due time), it is again conscious energy, now of another and loftier type, which later drags the deeps for their submerged treasure, and moulds the bewildering chaos into unity. But interposed between consciousness and consciousness is the well. And therein resides the peculiar significance of such a phantasmagoria as lies before us in the [Coleridge's] Note Book, the seemingly meaningless jumble of which we have tried to grasp.[20]

In striking contrast to this view, however, Werner W. Beyer, another Coleridge authority, emphasizes the role of the conscious and deliberate in the creative process. Writing in *The Enchanted Forest*, which the author says begins where *The Road to Xanadu* ended, Beyer states that Lowes' stress upon the importance of the unconscious "has given such wide currency to the concept of unconscious metamorphosis that its conscious counterpart has threatened to be ignored."[21] Beyer presents interesting evidence of Coleridge's use in his poetry of a crucial source until now undetected. This deals with the part C. M. Wieland's tale *Oberon*, translated by Coleridge around November 20, 1797, seems to have played in the genesis of *The Wanderings of Cain, The Rime of the Ancient Mariner, Christabel,* and *Kubla Khan*. Beyer has no doubt that Coleridge was aware of Wieland's poetry as a source of his own, since Coleridge translated the tale, and wrote this fact in a letter to Joseph Cottle.[22] Lowes, himself, in a letter of November 24, 1939, wrote to Beyer concerning this newly produced evidence:

Why, in view of the fact that on p. 243 of *The Road to Xanadu* I referred to S.T.C.'s flat statement that he was translating *Oberon*, I didn't go farther, I can't, to save my soul, imagine![23]

It was *conscious* judgment, Beyer insists, that led Coleridge to his discoveries of the potentialities of *Oberon*. More than Lowes suspected,

. . . conscious and unconscious appear to have collaborated and interpenetrated in the genesis of the fabulous ballad [*Rime*]. *As others have thought, the deliberate, purposive, and volitional appear to have played a far greater role in the complex process of discovering and envisioning, assimulating and transforming the multifarious stuff for its fabric and form.* . . . Oberon *makes it clear, I think, that the genesis of the* Ancient Mariner, *which it generously abetted, was not so largely a product of the subconscious as Lowes assumed.*[24] (Italics mine, L. E.)

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Beyer also cites another Coleridge authority, R. C. Bald, who,

> . . . after a study of the later notebooks [of Coleridge], similarly stressed what Lowes had seemed to minimize; the *conscious* element in the creative process, the deliberateness of Coleridge's reading, for purposes of poetry, and the recency of some of it which therefore could not have been long submerged in the subconscious. . . .[25]

Since it has been noted that the creative processes of a poet (Coleridge) may be compared to the creative processes of a scientist (Darwin), it is impossible not to see the parallel between these two geniuses in their working processes. *Oberon,* Beyer remarks, appears to have provided a scenario that Coleridge found

> . . . adaptable, kindling, and of high "symbolic potential." . . . It seems to have provided many materials, too, but, more important, to have served as a flexible form or matrix to help organize the richly diverse ingredients drawn from innumerable other sources and experience previously unrelated. And the conscious guidance it evidently afforded appears to put a somewhat different complexion on the story of the genesis of the great ballad, and at the same time to shed new light on various obscure passages.[26]

Coleridge once made the remark that men are caterpillars, very few of whom succeed in successfully transmuting themselves into butterflies. To introduce a bit of modern knowledge, one might observe that the caterpillar possesses glands in its head which at the proper moment assist him to make that beautiful transformation. In the case of men, even brilliant men, some outside incident, some catalytic agent concealed in the environment, may be the initiator of the transformation we call "creativity" or "genius." The man must be receptive, his mind afloat perhaps with the random forms which contain an unevolved future. It is then that the hidden key to the locked secret must be found. Otherwise the potential inspiration may drift past unrecognized into oblivion.

As *Oberon* was such a stimulus, a scenario for Coleridge's great poems, Blyth's articles on natural selection were conceivably Darwin's scenario, containing as they did the full series of stepping stones over which, as I have elsewhere pointed out, Darwin passed on his way into the new world of organic novelty. Lowes remarked as much of Coleridge:

> [In 1797] . . . a vast concourse of images was hovering in the background of Coleridge's brain, waiting for the formative conception which should strike through their confusion, and marshal them into clarity and order.[27]

In October or November, says Beyer, "the young poet-in-waiting

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discovered *Oberon,* and speedily began translating its teeming kaleidoscopic scenes—scenes which were *as if made for that service.*"[28] (Beyer's italics.) Coleridge may be compared to the young scientist Darwin, home from his voyage, freshly impressed with new lands and unknown creatures. Darwin suspected the reality of life's transformations, but he remained without a satisfactory mechanism to show how organisms were actually adapted to fit diverse environments.

Darwin wrote in his *Autobiography,* "Nor did I ever intermit collecting facts bearing on the origin of species; and I could sometimes do this when I could do nothing else from illness."[29] Then, said Darwin, he read by chance the work of Thomas Malthus in October 1838, and claimed to see in Malthus' work the key to natural selection in the animal world. It is, however, genuinely possible to conceive that it was the work of Blyth which Darwin, the scientist-in-waiting, read. Here was material which was, in the words of Beyer spoken in reference to Coleridge, "as if made for that service."

In the case of Coleridge, there exists a written admission that he was translating Wieland's *Oberon.* In the case of Charles Darwin, although he at no time mentioned Edward Blyth's ideas on natural selection,[30] interior evidence such as I produced in 1959 and which also appears in Darwin's *Second Notebook on Transmutation of Species* shows that he was fully aware of the papers which contained these ideas.

Fortunately Dr. Gerald Henderson of Brooklyn College has kindly allowed me to utilize additional evidence from his own recent unpublished investigations at the Cambridge University Library. Darwin's personal volume of *The Magazine of Natural History* of 1837 reveals annotations on Blyth's paper in Darwin's own hand. Moreover, a set of Darwin's page reminders which include Blyth's paper has been pinned to the inside of the back page. I will not encroach further upon Dr. Henderson's researches except to reiterate that Darwin knew and studied the 1837 paper he was never to mention in print. The volume at Cambridge is a presentation copy given to Darwin by Edward Charlesworth, its then editor.

Coleridge himself said: "Though [my mind] perceives the *difference* of things, yet [it] is eternally pursuing the likenesses, or, rather, that which is common [between them]."[31] The following lines were written concerning Coleridge. They could also have been written about Charles Darwin:

We have to do, in a word, with one of the most extraordinary memories of

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which there is record, stored with the spoils of an omnivorous reading, and endowed into the bargain with an almost uncanny power of association.[32]

J. B. Beer adds:

. . . from sources so widely separated in space and time, Coleridge had often elicited an image or a phrase which was infinitely richer than the sum of its source.[33]

Coleridge, far from defending the bathos of unconscious discovery, remarked with surprising practicality even in the midst of a commentary on sleep: "O then what visions have I had, what dreams —the Bark, the Sea . . . Stuff of Sleep & Dreams, *& yet my Reason at the Rudder.*"[34] (Italics mine, L. E.) He lists sensations, items of interest in his notebooks, just as does Darwin, but this is the stuff of poetry, not poetry itself, just as Darwin's associations of ideas and lists of sources are the stuff of science but not the completed act of reason.

As Professor Schulz has indicated, Coleridge was not engaged in séance writing. Neither, we might add, was Darwin. In his *Biographia Literaria* Coleridge remarks of poetic endeavor that much may be gleaned from travels, books, natural history, and that all may be acquired as part of the writer's trade but that these cannot substitute for the ear of genius. He does not forget Lamb's dictum that "the true poet dreams being awake."[35] The artist dominates his subject.

Similarly it was from no "sunless sea" of memoryless dream that Darwin drew his own illumination. It was more like being led across the stepping stones of a brook into an enchanted land from which the first intruder, Edward Blyth, had leaped safely back to "reality." Darwin, by contrast, a genius like Coleridge with "Reason at the Rudder," grasped immediately that he had come upon the long sought magic which would bring order amongst all his idle facts and relate them in a rational pattern. He saw a vision for which he was prepared, but which he might never have glimpsed save for his perusal of Edward Blyth. The weary world traveler had had to come all the way back to London to find his secret in an unread magazine.

The widespread popularity of the "unconscious" theory concerning Charles Darwin can readily be explained by the fact that a cult of hero worship has developed about the great biologist, such as frequently happens to a prominent innovator in any field.[36] Darlington, the British geneticist, has commented ironically: "Among scientists there is a natural feeling that one of the greatest of our

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figures should not be dissected, at least by one of us."[37] In the face of evidence that Darwin made unacknowledged use of material from Blyth, the theory of the unconscious is the easiest, most polite way of evading the exploration of a delicate subject. Numerous naturalists who would never treat contemporaries so gently under similar circumstances are eager to make a "sleep walker" of a scientist whose letters and notes are models of persistent conscious inquiry upon a great range of subject matter.

George Gaylord Simpson, referring to Darwin's statement in his autobiography that he "never happened to come across a single one [naturalist] who seemed to doubt about the permanence of species,"[38] and Darwin's belief that he owed no debt to his predecessors, said: "These are extraordinary statements. They cannot be literally true, yet Darwin cannot be consciously lying, and he may therefore be judged unconsciously misleading, naive, forgetful, or all three."[39]

Nora Barlow has also used the "unconscious" theory to explain her grandfather's denial that the subject of evolution was in the air. Doubtless Darwin's isolation at Down kept him from being aware of opinions from workers in other fields than his own, said Lady Barlow, "so that he unconsciously overlooked indications that belief in the permanence of species was waning."[40] Nevertheless some of the very journals he consulted contained references to the evolutionary hypothesis.

As opposed to the theory of the unconscious, it strikes one that Darwin was, in general, a keenly alert, conscious thinker, and he was so characterized by his associate, Thomas Huxley.[41] It is strange that in Darwin's *The Descent of Man* and *Variation of Animals and Plants Under Domestication*[42] all factual material drawn from Blyth was carefully listed but the two papers of Blyth concerning natural selection should be quietly ignored. It is difficult to accept this as mere coincidence. In *Variation* a footnote refers to the same volume of *The Magazine of Natural History* of 1835 in which Blyth's first paper on natural selection appeared.[43] Also a footnote in *Variation* states: "Mr. Blyth has freely communicated to me his stores of knowledge on this and all other related subjects,"[44] a somewhat cryptic and unenlightening statement. There is no possibility of doubt that Darwin used and studied *The Magazine of Natural History* in which Blyth's papers appeared.

Another odd circumstance has recently been brought to light by Gavin de Beer, even though he has refrained from any comment as to its potential significance. I refer to the recent disclosure that a

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number of pages are missing from Darwin's *First Notebook on Transmutation of Species*. The great importance of the *First Notebook* in tracing Darwin's early thought has been stressed by de Beer.[45] Yet fifty pages are missing from this *Notebook*, in which Darwin wrote on the first page: "All useful pages cut out. Dec. 7/1856/. (and again looked through April 21, 1873)."[46] Nothing was said about destroying the notes. As his son, Francis Darwin, pointed out in reminiscences of his father, Charles Darwin "felt the value of his notes, and had a horror of their destruction by fire. I remember, when some alarm of fire had happened, his begging me to be especially careful, adding very earnestly, that the rest of his life would be miserable if his notes and books were to be destroyed."[47]

De Beer, who reported in 1960 on these missing pages, said they had been searched for unsuccessfully in the Cambridge University Library, at Down House and the Royal College of Surgeons, and in the British Museum of Natural History. "The nature of their contents can only be surmised after a close study of the two hundred and thirty pages that remain," de Beer remarked, "and an estimate can be made of what is missing from the information and the argument."[48] Although there are some pages missing from the other *Notebooks*, it is those from the *First Notebook* that would seem to have the most bearing upon the origin of Darwin's theory, since it was begun in July 1837, before the date when he said he received his inspiration from Malthus. To reiterate my own words, I believe it significant that "Darwin opened his first notebook on the 'species question' in 1837. In January of that year Edward Blyth ventured the beginning of a second paper in which there is comment upon the principle of natural selection."[49] This comment, as we have seen, goes considerably beyond Blyth's first statement of 1835. It introduces, if briefly, the possibility of organic change. The name and work of Edward Blyth are not noted in the existing portion of the *First Notebook*, although they do appear in the *Second*.

"The idea of natural selection, so far as can be seen from the extant portions of the *Notebooks*, seems to have occurred to Darwin as a combination of the effects on him of the facts of variation, adaptation, and extinction,"[50] observed de Beer. Actually the missing fifty pages could have contained a great deal of information extending to Blyth's own views on these subjects. De Beer has avoided the suggestion that this fragmentary document may have contained more detailed references to Blyth's works. Since these pages compose the first part of the diary, their disappearance, taken with other

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evidence, cannot fail to hint of a genuinely "missing link" in the story of Natural Selection.

Much has been made by some of Darwin's defenders of his poor memory, though others have maintained it was prodigious. Huxley, who certainly knew him well, contended that Darwin had "a great memory."[51] Darwin himself remarked of his memory, that it "suffices to make me cautious by vaguely telling me that I have observed or read something opposed to the conclusion which I am drawing, or on the other hand in favour of it; *and after a time I can generally recollect where to search for my authority.*"[52] (Italics mine, L. E.)

It is also true, however, that Darwin did not have to depend upon memory, as he was a remarkably methodical man in his work. In discussing his work habits he mentioned the fact that since in several of his books he had used extensively facts observed by others, he kept

> from thirty to forty large portfolios, in cabinets with labelled shelves, into which I can at once put a detached reference or memorandum. I have bought many books, and at their ends I make an index of all the facts that concern my work; or, if the book is not my own, write out a separate abstract, and of such abstracts I have a large drawer full. Before beginning on any subject I look to all the short indexes and make a general and classified index, and by taking the one or more proper portfolios I have all the information collected during my life ready for use.[53]

One of Darwin's own statements, to which I have previously referred, strikes one as remarkably illuminating. In regard to an incidental matter of priority upon another biological matter which had occupied his attention briefly, he wrote in his autobiography: "It is clear that I failed to impress my readers; and he who succeeds in doing so deserves, in my opinion, all the credit."[54]

This statement is curiously revelatory to the perceptive student of character. There is involved in it a strange indifference to historical priority by a man in actuality highly sensitive on this score so far as his own great generalization was concerned. Was Charles Darwin engaged in psychologically justifying a philosophy which permitted him to dismiss forerunners from whom he had drawn inspiration—men like his friend, "poor Blyth,"[55] who "failed to impress" and therefore deserved no recognition from the world? One is forced to reflect upon this possibility, which has even been seized upon and brought forward by later writers as a justification of Darwin's attitude toward his predecessors.

There will always be an ineluctable mystery concerning the ori-

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gin of the theory of Natural Selection, just as there will always be a shadowy web surrounding the real Charles Darwin, a web unseen but as real as the black cape in which we see him enveloped in a photograph taken of him on the verandah at Down at the age of seventy-two. One of Darwin's most ardent supporters, George Gaylord Simpson, states with perceptive acuteness:

> The mystery persists. The man is not really explained, his inner adventures are not fully revealed in his own autobiography, in the family biography by Francis Darwin, or in the many other biographical sketches and books. There will always be something hidden, as there is in every life. . . .[56]

It seems to be an inescapable conclusion that the mystery lies concealed in the remarkable similarity between Coleridge, the "library cormorant," as he chose to describe himself, and Darwin, a similar cormorant observer of nature and of nature recorded in books. Each man had his catalyzer and both were reticent enough that it has taken over a century to find the catalyzer.

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14. When Dr. Dobzhansky proposed his theory in *The American Naturalist* he very graciously asked me if I would care to make a response. At the time, travel and administrative duties prevented me from accepting Dr. Dobzhansky's invitation. The present article exploring this subject was really stimulated by his generosity, and I am very glad to acknowledge this fact.
15. Dobzhansky, p. 205.
16. *Ibid.*
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18. There is a failure here, however, to distinguish between creativity in the arts and sciences and its traditional modes of expression. The poet is not called upon to footnote or to give the history of his ideas. The scientist by tradition honors and cites the significance of his precursors.
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35. Schulz, p. 104, citing Lamb.

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A version of this article appeared originally in *The Library Chronicle,* published by the University of Pennsylvania, Philadelphia, Vol. XXXI, No. 1 (Winter 1965).

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PHILIP H. ABELSON

Relation of Group Activity to Creativity in Science

BRAINS ARE our greatest resource, but we use them ineffectively. Few men and women develop more than a small fraction of their potential. When inspired, individuals can often do in a week what might require months at their customary pace. The discovery of ways to improve the use of talent would be one of the most important advances that science could make.

This challenge has recently elicited noteworthy contributions from a number of sources, including groups at the University of Utah and at New York University. Creativity, however, is a comparatively elusive target, and an understanding of the circumstances producing optimal creativity is still at a primitive stage. As creative insight is attainable only by individuals, most discussions of creativity focus on the individual and his mental processes. But in the realities of today's world, scientists who are creative rarely live and work in isolation. To some degree, all receive stimulus, information, and help in making judgments from others in their immediate environment. These interactions are highly important and, with the evolution of science, are becoming even more so. As a prelude to a discussion of the role of group interactions, I shall first review some of the steps leading to creativity in the individual.

The usual discussion of creativity follows Graham Wallas in presenting it as occurring in four stages. Herbert Fox has set them down in condensed form:[1]

1. *Preparation,* involving thorough investigation of the problem by reading and experiment.

2. *Incubation,* involving a conscious and unconscious mental digestion and assimilation of all pertinent information acquired.

3. *Illumination,* involving the appearance of the creative idea, the creative flash.

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4. *Verification,* involving experimental testing of the creative idea.

Recently Harold Hughes has added two steps which should be included.[2] His list is (1) interest, (2) preparation, (3) incubation, (4) illumination, (5) verification, and (6) exploitation.

In discussions of creativity most authors emphasize what is often the spectacular phase—illumination—perhaps because people are fascinated by the spectacular or possibly because of Poincaré's dramatic description of his own experiences. Though it is familiar from frequent quotation, a brief excerpt seems appropriate. Poincaré had worked fruitlessly for two weeks on the theory of Fuchsian groups and Fuchsian functions. Then, he says, "One evening, contrary to my custom, I drank black coffee and could not sleep. Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making a stable combination. In the morning, I had established the existence of a class of functions. There remained merely to set down the results and that was done in a few hours."[3]

Major creative flashes have been noted by many great scientists; undoubtedly they constitute an important phenomenon. Nevertheless, dramatic illumination, though representing a culmination, is for most scientists only one part, perhaps even a minor part, of creativity. The other five steps outlined by Hughes are also essential. Without the first three, interest, preparation, and incubation, there can be little illumination. In our generation the first two stages have assumed ever-increasing importance.

To be creative in science today, one must stand on the shoulders of giants. Many geniuses have already delved deeply into nearly every aspect of knowledge. As further opportunities arise, many fine minds quickly turn to exploit the new phenomenon. The probability that an unprepared mind will have a flash of illumination is practically nil.

The crucial element in creativity in science today is not dramatic illumination; it is judgment. When an experimental scientist seeks to be creative, he must make and implement a series of judgments. The complexity of his needs can be seen by looking at some of the prerequisite steps. First, he must decide upon an area to investigate. Obviously, this choice is crucial, for diligence which may be expended fruitlessly in one area might be richly rewarded in another. Having selected the major topic, the investigator must decide what to read, and how intensively. Some research scientists get lost in the morass of the literature, unable to make proper judgments about

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what to read, what to skip, what to believe, what to be skeptical about. Next, the scientist must decide what approach to take. Again, judgment must be applied, and even some creativity, for a uniquely good method is often the real key to major discovery.

Once he begins to experiment, the investigator faces more judgments. Are his methods really sound, or are there hidden defects in his procedures? Chance observations may suggest tantalizing byways; should he pursue them? Sometimes results that initially seemed valid are not satisfactorily repeatable; should he build a new, better apparatus to pursue his original goal, or should he turn to another problem? The creative scientist is daily faced with major and minor choices. Either he makes good choices as a result of deep thought and the use of every available aid of consultation, or he makes bad choices by default.

Only rarely is good judgment readily available. It requires a weighing of obvious alternatives and even the invention of new alternatives. Usually the best judgments come after wrestling with a problem in an environment free from distractions. In today's world, judgment and reflection are often crowded out by activities that represent more fun for the scientist—more experiments, administrative matters, committee work. In the face of the sharp competition of distractions, few scientists exhibit as high a quality of judgment as they potentially could. To exert good judgment requires self-discipline, which, in turn, rests on adequate motivation.

Motivation is essential to creativity; without it, even the best minds accomplish little. With adequate motivation comes the self-control necessary to draw on inner resources. Creative effort differs from most other activities in requiring unusual discipline. People in other walks of life may go for long periods without exercising much self-control. But a creative scientist must take himself in hand. The initiative must be his. No foreman call tell him how to think or what to do next. He has to do his own thinking and make his own judgments. Therefore he must organize himself and his activities. If he fails to exercise proper self-discipline, the deficiency may not be immediately obvious to others. He may appear for work at the usual hour, go through all the accustomed routines, attend seminars, read the literature faithfully, and give the appearance of creative effort. But, if his mind is elsewhere, his activity may be only a façade for inertia.

Related to the need for self-discipline are qualities of patience, courage, and willingness to take the punishment of disappointment.

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In the present era of science there is pressure to build extensive bibliographies. The easy way to do this is to carry on research that is merely a small extension of what is already known. Then the scientist does not have to think very deeply; he can let a technician perform the work; and at the same time he feels some security as a contributor to science. Little creativity emerges from such a procedure. The path of courage lies in choosing a difficult but fundamental problem and working on it even though the walls of confusion seem insurmountable. The person who undertakes such a task must be capable of living with disappointment. He must be able to cope with the unhappiness that follows failure of what seemed to be promising approaches. Even after an extended period of work from which there is no obvious accomplishment he must be able to summon the stamina necessary to persist in his efforts. The inner resources on which the creative person calls in order to continue after repeated failure can be tapped only by deep motivation.

How are people motivated? To that question there is no single easy answer. First of all, the great variation in the intrinsic capacity of individuals to respond to motivating stimuli must be recognized. Little can be done with a man devoid of character. The capacity to be motivated has its roots in genetics and is nurtured by environment. The contribution made to motivation by the home environment in early childhood is well known. Many, perhaps most, creative scientists come from families in which the father engages in professional activites. Obviously, the children in such a family are reared in an atmosphere in which knowledge has a high value and excellence is considered a way of life. Another stimulus can come from a teacher who inspires an enduring love of knowledge and an insatiable thirst for learning.

Experiences that enhance motivation do not stop with formal schooling. One of the most effective agents is mutual stimulation arising from the interaction of two or more individuals. Given the right circumstances, human beings can interact in extremely constructive, helpful ways. Interactions can produce enhanced motivation; they can also provide other factors (judgment, for example) that are essential to the creative scientist.

Some of the benefits to creativity arising from group interactions have been reviewed by Likert.[4] Although his book was concerned mainly with means of improving management of commercial and business activities, many of his ideas nevertheless seem at least partly applicable to scientific creativity. For example, he empha-

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sizes the potential helpfulness of the group in providing motivational support. The role of groups in scientific creativity does not seem to have been probed frequently or deeply. Accordingly, I shall present some anecdotal material which indicates the high importance of human interactions in creativity.

For years I have been impressed by the enormous scientific contributions of three Hungarians—John von Neumann, Eugene Wigner, and Leo Szilard. Since all came from Budapest, I recently asked Professor Wigner about possible interaction among them. He told me that there was a strong mutual stimulus. Wigner and von Neumann had known each other during high school days in Budapest. Later they had both gone to college in Berlin. Being foreigners, and not feeling part of the social structure, they became especially close. Professor Wigner had told me earlier that he learned more from von Neumann than from any other man, and though Wigner would be modest in his estimates, I am sure that von Neumann learned a great deal from Wigner. Later these two became associated with the highly imaginative and stimulating Leo Szilard, and the three were very close. They found excitement in ideas and mutual stimulus in arguments and discussions with one another. Finding their surroundings uncongenial, they discovered in creative science a perfect vehicle for escape from the rest of the world and, at the same time, a wholly satisfying common ground for excitement.

Dr. Wigner, in discussing the matter of creativity with me, emphasized this matter of discontent, of the importance of not quite fitting into the environment. He also suggested that perhaps the success of two Nobel prize winners, Lee and Yang, resulted from a relationship similar in pattern to that of his relationship with von Neumann, and Professor Yang has confirmed the surmise. Lee and Yang had known each other in China during the forties. They reestablished contact at Chicago in the late forties. There was an intense interaction, which was later noted at Princeton. It had a highly constructive influence and contributed much to their subsequent success.

Another famous example of constructive interaction involved Enrico Fermi and a group of physicists in Rome during the late twenties and the thirties. Fermi first began his work in Rome in 1926 shortly after obtaining his doctoral degree at Pisa. In the preceding generation there had been no first-class physicists in Italy. Yet in a few years there gathered around Fermi men who

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were to gain reknown. Fermi himself, moreover, was to become one of the greatest physicists of all time. When the group began to interact there were only a few indications of future greatness. Fermi had already shown signs of being an extraordinary man. His first associate, Franco Rasseti, even in graduate school showed a touch of genius. However, Emilio Segré, who was later to receive the Nobel prize, was still an undergraduate, as was Edoardo Amaldi, now one of Europe's leading physicists. Fermi, of course, was the leader of the group, but there is little doubt that he was stimulated by the others and that they in turn benefited from association with him. The group was much stronger than the sum of its parts. Moreover, the stimulus of working together for a time had a permanent beneficial effect on all the members—an effect that lasted long after the vicissitudes of politics and war broke up the close interaction.

In this area I have had three personal experiences. On a lesser scale, they nevertheless had considerable effect on my life. During my childhood I lived in an area of the city that for years had not produced a college graduate. A group of my playmates interacted most favorably with one another. We had science projects in an era when almost no one paid any attention to science. We engaged in friendly rivalry to outdo one another. All the group went to college —not to do so would have led to unthinkable loss of face. And all have achieved considerable success. One of the men is a leading cancer surgeon and regent of a state university; one has won national recognition as an architect and heads his own company; and another is chief mechanical engineer of a petroleum company.

A second experience gave me a chance to contrast some aspects of individual and team research. I spent four years (from 1935 to 1939) at the Radiation Laboratory at Berkeley as a graduate student in physics. To this laboratory came a score of some of the best young scientists of that day—Luis Alvarez, Edwin McMillan, Glenn Seaborg, Emilio Segré, and others who have had fine careers. At that time probably no laboratory in this country had a more talented group. Professor Ernest O. Lawrence, the director, had two goals: to develop his cyclotron, and to encourage exploitation of its potentials in research. Development of the cyclotron was a task requiring a team approach, and Lawrence was captain. The rest of us, particularly the graduate students, were just so many pairs of hands. While working on the cyclotron we had almost no opportunity to be creative. Indeed, innovation on the part of graduate students was

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often detrimental to the team effort. Altogether, the experience in the Radiation Laboratory would have been miserable and stultifying had it not been for Lawrence's second goal of encouraging research employing the cyclotron. In this area, organization of the effort was entirely different. Lawrence was enthusiastic and encouraging in his support of research by the staff, but he made no effort to go beyond giving helpful suggestions. The experimental activities were largely conducted by individuals or by pairs. New results were greeted with enthusiasm by all the laboratory personnel. The eager group of physicists present provided helpful suggestions, judgment, taste, and knowledge of the literature and technics. In the hours when an individual was free to conduct his own research, the laboratory was an excellent environment for creative effort. The contrast in the creativity of the men while engaged in team research and in individual research could scarcely have been greater.

As a result of this experience I became wary of team research. Observations during twenty-five years have not caused me to alter my attitude. Team research is useful when specific goals can be outlined in advance. A team effort may be the most effective approach when only a few members are capable of creative thinking and they are responsible for directing the work. In the exploration of the unknown, however, teamwork usually suppresses initiative. Prolonged experience as an underling on a team contributes little to the development of an individual and may even be harmful.

A later experience of group interstimulation proved very valuable for me. Shortly after World War II, three other nuclear physicists and I joined with a biologist to form a biophysics group at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The physicists knew no biology and almost no chemistry, and it was ridiculous to attempt biophysics research in a department devoted primarily to geophysics. Professional biologists and biochemists who learned of our activity felt free to make caustic comments; in fact, one distinguished biochemist was heard to describe us as "a group of wistful physicists contemplating the mysteries of biology." At the same time our former colleagues in nuclear physics shook their heads sadly at our insanity in abandoning an established professional position to embark on such a foolish venture. The semi-hostility of the outside world helped knit the group together. Naturally, we were under all manner of pressure to establish a niche for ourselves and to win the respect of a new body of professional colleagues. Embarking on a course of self-

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education, we taught each other physical chemistry, biochemistry, and microbiology. Our conversation and our thoughts were centered on the experimental work we were doing and on its interpretation. While each usually worked on his own individual projects, all helped one another in many ways—with suggestions, enthusiasm, and judgment. We gave mutual support by fostering the concept that all of us were doing important, exciting, and significant work. We felt lucky to be having so much fun while being paid for it. Soon we were pioneering in studies of biosynthesis in microorganisms, and in a few years we were making worthwhile contributions. Our book entitled *Studies of Biosynthesis in Escherichia coli* came to be regarded as an outstanding text for students of microbiology.

These examples of mutual stimulus could be multiplied. Most of us are responsive to our environment, and group stimulus seems to be one of the best means of enhancing creativity. In the examples I have cited there are several components that I believe to be essential. First, there is a banding together of individuals to create a microenvironment which offers intellectual satisfactions to those within the group and which also meets the need for human fellowship. It is then possible to adopt the attitude that the value system of the rest of the world does not really count, that a common interest in advancing an area of science is the most important and only tenable activity for the members of the group. Moreover, if an individual temporarily loses his élan, he can soon regain it, for at all times there are some present who are brimming with infectious enthusiasm.

Judgment can usually be sharpened through group interactions. Related to this is the matter of "blind spots." A man may think deeply about a problem but fail to solve it because he lacks some small crucial idea—an item of knowledge, perhaps—or makes a slight error in analysis. Discussion of the problem with others can provide the single item that opens new vistas of comprehension.

Bringing a group together does not invariably produce this favorable mutual stimulus. Men who have the capacity to create must have their share of pride and egotism. In a closely knit, tight environment, tensions and rivalries are always latent. Indeed, the greatest hazard in group activity is internal dissension. When tensions begin to rise, creativity is brought to a standstill. A person engaged in a serious personal clash of wills invariably gives first priority in his thinking to the matter at issue. All too often the conflict escalates to implacable hatred, to the detriment of the in-

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dividuals directly involved and all those around them. The carping critic, the jealous troublemaker, often destroys far more than he creates, and his evil influence can wither the creativity of many around him.

The tendency toward dissension can be countered in various ways. It is necessary that the individuals become so desirous of accomplishing common goals that they suppress their natural egotism, or, alternatively, each must receive so many benefits from an association that he believes self-interest requires a smooth relationship.

One clear-cut example of a common goal is seen in wartime, when national energies are concentrated to meet a common foe. Those who worked in the great wartime laboratories remember that the activities were relatively free of the usual frictions. In some of the examples of interaction previously cited there was a common element of group unity in the face of an unfriendly or drab environment. Rivalry between institutions can be another healthy way of promoting internal accord and common purpose.

An effective means of ensuring peace within a small group lies in the choice of its members. They should be people whose background and temperament are different. One, for instance, may be a skilled experimenter, and another a great enthusiast who spouts ideas. A third may have excellent judgment and the ability to recognize what leads are likely to prove valuable and to dispose quietly of the trivial, unsound, or sterile ones. It is usually desirable that the group contain a compromiser or peacemaker, as well.

It is also desirable that the various members of the group have somewhat differing bodies of knowledge so that they can teach one another. By assembling people of sufficiently different competence, almost encyclopedic knowledge can be provided in even a small group. Individuals having different talents and knowledge are intrinsically less competitive, for each has the security of knowing that he has a special contribution to make from his own particular area of strength.

I should like to touch on another mode of group stimulus that has proved effective, namely, the small, interdisciplinary, closed symposium. In an ideal arrangement, some twenty individuals meet for three days at a secluded spot where the rest of the world cannot intrude. The topic of the meeting should be an important one which draws on a number of different areas of knowledge. The key to success in such a meeting is to place individuals in close and agree-

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able contact with other creative scholars whom they have not previously met and to facilitate the juxtaposition of ideas in combinations that have not been made before.

The problem of achieving stimulus from larger group interactions among scientists has become progressively more acute. Large national meetings have ceased to fill the role they once had. Attendance at a huge gathering generally brings neither satisfactions nor effective transfer of ideas. To maintain the health of science we must find means of restoring the stimulating quality of interactions among larger groups. I believe that special symposia are one of the best answers to this need.

The general quality of the intellectual atmosphere of the community environment may also have a considerable effect on a scientist's activities. There is a marked variation in this factor. I, for example, find the intellectual atmosphere in Boston stimulating. New ideas are in the air, and they are received with enthusiasm. On the West Coast there is also a favorable climate for innovation. The midcontinent is not nearly so receptive or interested in intellectual matters. New York resembles Boston, but Philadelphia seems fragmented by rivalries and antagonisms. Intellectually, Washington seems to me curiously dull—sometimes apathetic.

I have mentioned some nearly ideal situations in which highly motivated individuals like Poincaré have succeeded in tapping the subconscious, or geniuses like Fermi have achieved great things, and persons associated with them have received a life-long stimulus. These ideal situations come rarely, and most individuals receive lesser stimuli from their environments. Even so, some constructive steps can be taken and some pitfalls can be avoided.

Highly intelligent, highly motivated individuals with natural good judgment can probably attain creative insights in almost any environment. Most people, however, are much influenced by surroundings and the circumstances under which they work. In any research effort there are usually periods of relatively routine work, and often they are essential. The crucial effort, however, is that which goes into judgments of interpretation and decisions of what to do next, especially the decision to embark on innovation. The quality of such decisions is highest when they evolve from intuitive insights. Every man I have known who is markedly creative has devoted a substantial part of his time to thinking about his work. The really good men achieve some of the total immersion that Poincaré cited. I believe that such complete immersion in a problem,

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at least periodically, is essential to developing a person's best potential.

In our efforts at organizing research we probably make our greatest mistakes in failing to provide for the need for total immersion in creative thought. In choosing group leaders, section heads, and others higher up on the administrative ladder we select men who have demonstrated ability as creative scientists. We then saddle them with the need to make a continuing series of major and minor decisions, and provide them with an ever-ringing telephone and a chattering distraction for a secretary. In the process we destroy most of their potentiality for creativity.

From my personal observations I would suggest that research administration be organized so that all creative individuals have frequent opportunities to attain total immersion in technical problems. Administrative responsibilities, if they have them, should be attended to periodically but with free spaces in between. Creativity should not be thwarted by incessant petty distractions. Also, for many individuals, there is a seasonal variation in creative capacities. During these periods they should try to avoid making interfering commitments and devote as much time as possible to laboratory work.

Many scientists find it useful to have two or three deadlines to meet each year. At our laboratory we have an annual report that we take very seriously. The report, a technical discussion of all work that has made substantial progress during the year, is sent to more than two thousand persons and establishments throughout the world. When the deadline for it approaches, our staff puts on a tremendous spurt of effort to complete studies for inclusion in the report for that year. Another type of deadline occurs as the staff prepares papers for technical meetings. On these occasions there is another burst of effort, and men turn out several times more work than is their usual custom.

I have discussed some of the factors that go into making a creative scientist and providing him with a favorable environment. Some of the factors are genetically controlled. Others depend on family background and early training. In choosing staff we want to recognize men with brains and character who are motivated to achieve. Then we must do our part by providing a combination of challenges and deadlines coupled with periods in which there is freedom from distraction, preferably for weeks at a time. Finally, we must endeavor to provide the kind of climate in which negative

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aspects of group interaction are suppressed while new ideas and contributions are received with enthusiasm. We should seek a situation in which the individual has maximum opportunity to tap his own resources but in addition is helped and sustained by the stimulus of close associates and the broad environment.

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J. DOUGLAS BROWN

The Development of Creative Teacher-Scholars

ALTHOUGH THE general public, and even Congress, may accept the assumption that quantity and quality move in parallel, anyone with responsibility for the assurance of excellence in any human endeavor soon learns that size and quantity are very mixed blessings in fulfilling their purpose. There is no area in which this is more true than in the development of creative talent for the learned professions. More specifically, size and quantity will not ease the task of providing creative teacher-scholars to man the faculties of our liberal universities in the face of rapidly increasing enrollments.

The difficulty of developing creative teacher-scholars in adequate supply lies in the nature of the persons potentially qualified to assume the role. We have no reason to believe that there is a fixed proportion of candidates per hundred-thousand live births, let alone an *increasing* proportion as the needs of the world expand. It is necessary, therefore, to learn how to nurture with the greatest possible insight the precious flow of potential talent which is discovered and started upon the long road to full productivity. In considering this problem, it may be helpful at the outset to examine the nature of the creative teacher-scholar. Since most of the subjects to be analyzed are too busy in their chosen disciplines to examine themselves, it falls to a dean of faculty who has observed them for many years to present some conclusions on the attributes of the creative teacher-scholar.

A distinction should be made at the outset between the creative teacher-scholars who provide the vital core of a dynamic teaching university and those very learned persons who spend their lives in accumulating vast erudition for its own sake. A creative scholar provides a flow of new ideas, drawing upon deep resources of accumulated knowledge. Further, the art of teaching is itself creative, if well performed. The teacher must constantly find new ways to

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communicate old ideas and new ideas and to nurture the development of ideas and understanding in his students. The excitement of the teacher-scholar in the creative process and ideas carries over into the excitement of helping others to gain deeper insights. The scholar who is not also an active teacher may become very learned but, without the stimulation of the teaching situation, often comes to respect the authority of past scholars at the expense of his own creativity. It is true that fields of knowledge vary in respect to the degree to which new ideas and new approaches can be developed, but the creative teacher-scholar can be distinguished from the merely "accumulative" scholar in any field.

A further premise should be made clear. Since the distinguishing qualities of the creative teacher-scholar are essentially *subjective* in nature, it is most difficult, and perhaps futile, to attempt to design a research project in which these qualities must be precisely determined and validated. The determination of a single attribute in the person studied would be no better than the judgment of the investigator. Dependent upon the response of the subject in the presence of the observer, the evidence may become self-consciously autobiographical and impressionistic rather than scientific. When a mixture of attributes developing over a whole life span is involved, the problems of validation become enormous. Few people can understand or remember just how they became what they are. Therefore, the following propositions are based on the *judgment* of a single observer whose chief responsibility for many years has been to help in the selection and evaluation of creative teacher-scholars.

I. *The Attributes of the Creative Teacher-Scholar*

An inquiring mind. This is a native quality in the creative teacher-scholar, enhanced from earliest education onward. It is a tone of attack stimulated by both informal and formal education in all areas of interest. If the native quality exists in high degree beyond the natural curiosity of the child, family influences may have much to do with its early maturing. The fact that many creative scholars grew up in academic families is not an accident. Both heredity and environment have had their effect. In the young person of inquiring mind, the "why" must be answered as well as the "how," and the parent or teacher who is also interested in the "why" reinforces a growing hunger for knowledge.

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The nature of the essential drives which cause a high degree of motivation toward inquiry in some individuals of apparently similar backgrounds and not others remains a fascinating mystery. A desire for status or evident accomplishment is often present. But the love of inquiry in the truly creative scholar is what carries him to a level of high competency and lifts him to the sustained exploration of the great unknowns. Since the early environment of creative men varies so widely, one is led to believe that the larger share of elements which bring success are in the person himself and can be developed only in an atmosphere of a specific and individually appropriate kind. This suggests that there may be a strictly limited number of persons of high creative potential and that not all will become effective unless they receive the individual attention of an inspiring teacher. This would explain the marked success of a number of smaller colleges in starting able young scholars on their way.

That a high potential for mathematical analysis appears earlier than other aptitudes is fortunate in an age when creative mathematicians are greatly needed. It would be a serious loss, however, if the early maturation of interest in mathematics, or even in science generally, channeled individuals into the field of their first love when they might contribute even more in the social sciences or the humanities. It is a function of liberal education to give opportunity for range and excitement in inquiry in many fields and for understanding the diverse approaches in seeking knowledge and understanding. Time and again an underclassman who has excelled in mathematics, physics, or chemistry finds economics, history, or philosophy even more exciting. The same love of analysis which made mathematics a challenge carries over into less abstract disciplines as the individual realizes the complexity of human affairs. Liberal education in breadth is necessary to help students of high potential to find the field in which they have a comparative advantage, even though they could succeed in several. It is also valuable for society in spreading talent over the many areas in which creative persons are needed.

It is my experience in dealing with many creative scholars that liberal education serves to sustain the drives toward inquiry through life. Years of specialization in a narrow field of learning sometimes cause an individual to "go stale" if a broad resource of interests does not exist. Such breadth of interests is more likely to develop early in one's education. If opportunity has not been given to or accepted by the talented person at this time, he may lose in later years the

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stimulation of mind and spirit and the catholicity of appreciation which sustains the truly creative teacher-scholar through the forties when many able men level out. A sabbatical leave will not overcome the staleness of long overspecialization. This, I believe, is a special problem in mathematics. Physicists have sometimes welcomed involvement in national policy as an antidote to long-continued concentration in theoretical analysis.

The powers of analysis and accumulation. This is the ability to acquire, understand, evaluate, and retain knowledge in an orderly manner. The human mind has tremendous powers of assimilation of experience in all its forms. Unlike the animal, it can far outreach in its retentive powers the range of experience which is useful in day-to-day survival. The important difference which marks the creative teacher-scholar is that his experience or new knowledge, at least in significant areas, is not merely acquired like impressions of a passing landscape or a moving picture, but is by habit analyzed, evaluated, and understood at the time it becomes a part of his mental resources. A potential teacher-scholar unconsciously or consciously is attempting to create within himself an orderly library of knowledge from which retrieval is facilitated by sustained self-training.

In the maturing teacher-scholar, analysis and accumulation become a way of life—an intellectual habit. This approach is strengthened by education and training under conditions which question hasty or partial answers to difficult questions and which demand an organized and responsible consolidation of knowledge. This is why the education of the teacher-scholar of high potential can seldom be effective in an environment stressing only accumulation of knowledge and not interaction among colleagues. Analysis can be carried part of the way by the solitary, inquiring person, but he also has a great need for the teacher who questions easy answers, or fellow students who make him defend his position.

Unfortunately for those who propose new economies in higher education, constant, vigorous interaction between minds is not consistent with mass instruction. Like TV or movies, lectures can communicate a great deal of knowledge to large audiences. But lectures are no substitute for the expensive process of helping the individual student hammer out an analysis of values, relationships, judgments, and proofs in his own mind. This is true education. It is an essential element in the development of the creative teacher-scholar, and some institutions must assure its availability no matter

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how expensive it may become as students flood our colleges and universities.

The need for constant interaction of inquiring minds does not stop with the attainment of the Ph.D. University faculties, to be productive, must provide a climate and process of mutual interaction to assist each member in his life-long career of analysis and accumulation. Easy answers are not the monopoly of the unenlightened. The physicist, the economist, and the classicist need the cross-criticism of colleagues and the polite doubts of students to prevent mastery from becoming arrogance. This introduces the problem of critical mass in the developing of sources for new creative teacher-scholars. Unfortunately for those who seek a rapid expansion of supply, the university environment which produces teacher-scholars of high talent must itself have a critical mass of both able teachers and able students.

The absence of a critical mass in some fields of learning has constituted a problem for many universities. Until recent years, astronomy suffered from the relative isolation of the few professors which each university could afford. In an attempt to compensate for this, the discipline developed arrangements for intercommunication between universities, and visits to the great telescopes became a normal way of life. Despite this, the profession was not able to attract and develop any considerable stream of new talent until recent governmental interest in astrophysical sciences provided support for a much larger group of teachers and advanced students. At the other end of the spectrum of knowledge, the ancient languages continue to need the dedicated efforts of a few universities to assure an adequate flow of new scholars. The teaching of the classics in translation has helped to justify costs, and also to prevent professors from becoming "accumulative" scholars alone.

It would be a fortunate development if isolated research centers which are organized to produce immediately useful findings could be relied upon to develop a flow of creative talent to augment that provided by the universities. While exceptions such as the Bell Laboratories exist, it is becoming apparent that such research centers usually absorb more talent than they produce. A university, no matter how productive its faculty may be in contributing new knowledge, remains essentially man-centered. An industrial or governmental laboratory must be product- or mission-centered to justify its costs. The development of creative talent seems to require the climate of academic freedom in which teaching is as important as

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learning, and where the process of discovery is as important as its product. Even in the most carefully planned institutes for advanced study, the absence of a teacher-scholar relationship appears to be a handicap rather than an asset except for the short-term visitor on sabbatical from teaching.

The attribute of intuition. This is what makes a truly creative teacher-scholar. It is a mysterious quality of subconscious association of ideas—the combination of ideas to form new ideas. It is, however, creation *from* and not *against*. It requires a vast complex of accumulated knowledge and ideas which have been assembled by an inquiring mind. A great body of such knowledge and ideas, especially in one's discipline, must have been analyzed and evaluated over past years. But it is important to recognize that by no means all, or perhaps even a major part, are the ideas in a narrow segment of knowledge or experience. Creativity is a mysterious process. It involves discovery and not logic alone. It grows out of accumulated experience, but it transcends the conscious analysis which made that experience useful.

The intuitive instinct in a potentially creative teacher-scholar can be dulled by his own habits of mind or by his environment. To range widely requires the courage to break with convention, to avoid undue respect for authority, to keep logic in its proper place, and, above all, to avoid over-concentration in a single field of experience. A firm basis of liberal education is a vital resource for a creative person. The interplay of ideas and approaches from many fields of learning and human experience enriches and strengthens the resources for creativity.

Environmental factors militating against sustained creativity among teacher-scholars are all too common. Intuition can be crowded out by immediate personal concerns, detailed administrative tasks, frustrating responsibilities, and demands for too-early demonstration of results. Academic freedom, in the last analysis, is the freedom to think intuitively about all possible answers to man's questions about the unknown or the unresolved. Logical analysis may provide the basis for lectures and for many of the published papers which fill the journals. Free-ranging intuition takes time and may show limited results. The liberal university should provide the time and the freedom for it, once the teacher-scholar has indicated potential talent. This involves not only many practical arrangements in daily existence, but also a propitious climate which evolves over many years.

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The great emphasis which I have placed upon the attribute of intuition in creative teacher-scholars may suggest that I am limiting this category of persons to a small but precious minority of those holding professional rank in American universities. If one is looking for the complete and balanced model, this is true. Few professors attain the intuitive brilliance of a John von Neumann. But there are many others who in their own way and time demonstrate the intuitive qualities which lift them above the rank and file of the larger number of solidly competent teachers and scholars who make higher education feasible on the American scale.

But excellence in teaching as well as excellence in scholarship requires intuition. A liberal university is always seeking men who have this quality, even though the precise term is seldom used. Perhaps it is the pragmatic strain in American culture which reserves "intuition" for poets and women, and assumes that those responsible for the important affairs of the world should be logical at all times. All one can counter is that the discovery of most of the great ideas of the world and the contributions of its most influential leaders involved intuition and not logic alone. A university can disregard this fact only at the risk of losing the excitement and vitality which are its peculiar heritage.

The attribute of self-discipline. In the cycle of creative work, the freedom of mind and spirit which enhances intuition must be preceded by *and* followed by sustained concentration—*before,* to prepare oneself, and *after,* to distill and re-distill, test and retest the new idea which intuition has produced. This requires a persistent quality of self-discipline, an ability to change mental gears from analysis to intuition to analysis again. It separates the truly creative scholar from the brilliant "idea man." It marks the scholar whose efforts provide an essential contribution to the general body of knowledge rather than remain interesting hypotheses. The testing of ideas may be reinforced by the anticipation of criticism by others, but in the truly creative teacher-scholar it involves a sustained quality of self-criticism.

At its best, the doctoral dissertation is an excellent example of the analysis-intuition-analysis cycle in the process of creative scholarship. At its worse, it becomes a tortured accumulation of material on some minor item in the encyclopedia of knowledge. In any case, it requires self-discipline on the part of the prospective scholar. Universities have been criticized for making the doctorate a union card for membership on their faculties. So far, no one has

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invented a better method of discovering whether a candidate possesses the required quality of scholarship. Whether the doctoral dissertation is the first or the last experience in protracted, analytical self-discipline divides the creative scholars from the pack. The element of excitement which intuition brings to the cycle of scholarship seems to make the difference. Where this exists, the goal becomes worth the effort, not once, but repeatedly throughout life.

A tendency toward perfectionism. It has been said that the final test of truth is esthetic. In the universe of knowledge, there is no great master-teacher on this earth who corrects and grades the papers. A creative discovery in any field, it seems, must have elegance, simplicity, symmetry, or "perfection." A teacher-scholar must have faith that there is order in truth, once the many complexities are understood. In seeking that order, he comes to reflect his goal. He becomes a perfectionist not only in his chosen discipline, but in other areas of living, sometimes to the point of irritation for those who want him to be practical. Unfortunately, at times, the teacher-scholar in a more abstract discipline fails to realize that university operations, like those in all human organizations, require compromise and mutual accommodation.

It appears to be necessary for deans and departmental chairmen in dealing with the creative teacher-scholar to remember that, in their official capacity, they do not have the privilege of private irritation. The unconscious assumption that space, staff, library services, and equipment should be available in neat balance as the scholar needs them can be exasperating when budgets have been disregarded and practical limitations discounted. But the true perfectionist is not dismayed and persists in expecting rare foresight and generosity in all those who support his work.

A tendency toward introspection. The most complex and productive laboratory in the world is the human mind. Those who work in that laboratory most intensively are likely to determine many of their judgments and attitudes for themselves, even to the point of stubbornness, rather than depend upon the views of others. This is not always a source of happiness, especially in the perfectionist, the self-critic, and the person of intuition. It is not always helpful in one's personal affairs. There is concern about where one stands and about one's accomplishments.

It is a part of the function of a university to provide a sense of security and status for creative teacher-scholars. The attitude of the general public toward professors has changed greatly since their

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contribution to scientific and engineering progress has been made apparent. Economists are beginning to be recognized as useful in public policy. But there remains a large proportion of the disciplines on any campus in which men will study and teach throughout life without benefit of public notice. The status of professor in the particular university will be recognized both in the academic world and in that segment of the public which is most meaningful to him. The separate ranks of assistant, associate, and full professor may seem unnecessary refinements to those outside academia, but within, they are a means not only of encouraging achievement but of registering it so that all may see. The creative teacher-scholar whose subject does not lend itself to textbook-writing or consulting must depend upon recognition by his peers and upon the regard of those few outside the academic community who can understand his work. As an introspective person, he needs some formal recognition of status within the university in those times in life when new intellectual accomplishments are not obvious, even to those close by.

A tendency to resist external authority. The creative scholar tends to resist the judgments, standards, and criticisms of others unless he respects their previous contributions. This leads to a more or less conscious discounting of advice from any authority based on hierarchical status alone, whether in the university, industry, or government. As all presidents and deans well know, there are strict limits to their authority, once a faculty member attains tenure. Large areas of university operation depend upon colleague authority for direction and control, for universities are essentially systems of partnerships, housed, financed, and kept out of serious trouble by patience and understanding.

To avoid the impression that university administrators are passive servants arranging things to make life simple for great minds, it may be well to remember that the majority of effective presidents and deans are also teacher-scholars, or were at one time. From their own experience, they understand why their colleagues act the way they do and are convinced, at least in their more philosophical moments, this this is for the best if the creative work of the world is to be done. Yet, there are innumerable decisions in the development and functioning of a faculty which cannot be left to protracted and undisturbed analysis, to intuition, or to uncompromising perfectionism. Fortunately, most teacher-scholars recognize this, especially in an institution which must educate thousands of young persons, provide salaries, plan buildings, and support research.

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It is also true that university administrations in America have developed a body of experience—one is tempted to say an art—in creating an environment for creative teacher-scholars which justifies, in some institutions at least, the respect of a large segment of the faculty. The more useful elements of this experience have evolved out of years of interaction between members of faculties who remain teacher-scholars and those teacher-scholars who try their hand at administration. Not infrequently, a lawyer or industrialist takes on the arduous task of presiding over a university. Some have performed miracles of organization. Others, like the invaders of China, have been absorbed into the faculty way of thinking. Still others, to the relief of all concerned, have moved on to less demanding positions. It appears that some service as a professor provides insights, or at least good hunches, which enhance survival.

II. *The Development of a Faculty of Creative Teacher-Scholars.*

Neither space nor ingenuity permits a precise demonstration of the way in which a faculty of creative teacher-scholars can be developed and nurtured. Several approaches or means can be suggested, but the best way to learn how to administer a university is to take charge of one.

As has been suggested, the nurture of a creative teacher-scholar begins in childhood and is carried forward in school and college. The succeeding levels of education provide not only a preparation for creative work but a continuing system of tests of motivation and attainment. The crucial screening comes in the last years of college and the first years of graduate work. It is at this point that accumulation gives way to independent creative skirmishes with ideas and approaches. There is a cycle of education in *conformity,* of learning what is already known, which is succeeded by education in *creativity,* of seeking to find out what is still to be discovered. The best institutions of higher education, and the best teachers, wherever they are, sense this difference clearly and recognize the need of the student of high potential to move ahead into the more challenging period of a creative approach to self-education.

It is for this reason that the recruitment of potentially creative teacher-scholars depends heavily on the recruitment of young people by good universities from good colleges whether within universities or not. The student-teacher relationship is the catalytic agent

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which continues to be important until the doctorate has been completed. If teachers have little contact with individual students, the latter are far less likely to gain the help and the motivation necessary to persist along the road to excellence. Moreover, with little individual contact, the teacher is ill-prepared to perform his part in the highly selective process of judging both the mind and the spirit of the young person who has potential for creative scholarly work and should be urged to invest years in graduate study.

Once the Ph.D. is attained, the recruitment process in building a faculty of creative teacher-scholars becomes the joint task of the peer group in a discipline and of the central administration of the university. The peer group in a good university is on a constant quest for exceptional talent and should have an appetite limited only by the administration's sense of economy and balance. The peer group must emphasize potential ability as well as achievement, willingness to cooperate on a team as well as to work alone, and a desire to teach as well as to learn. The central administration, besides assuring means, need, and balance, has a basic obligation to make certain in each individual appointment that the candidate, as a person, understands and accepts the obligations of membership in this sensitive, self-administering human organization. If a university needs both good laws and good manners to survive, the time to judge good manners in their largest sense is when a new member is appointed.

The heavy reliance upon the judgment of peer groups in the selection of new members involves countervailing pressures which must be resolved if an effective faculty is to be assured. A very natural tendency of both departments and universities is to hire established scholars of high visibility who may have passed their period of greatest contribution and who prefer to spend their remaining years undisturbed by students and less mature colleagues. This form of investment in talent for the sake of public image is expensive not only in dollars but in faculty morale. Within the peer group, and especially among younger colleagues, the aura of the "great man" wears thin as others must carry the load he avoids. Only if such a scholar serves as an exciting catalyst or a wise and patient critic is the investment worthwhile, for a creative faculty is much more than a collection of solo performers. The central administration has the obligation to question the "stamp-collecting" tendencies of an ambitious department and to exercise restraint on its own part.

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On occasion, the reverse of this trend appears in peer-group selection of members for promotion to higher rank. This is the desire to be kind in a short-sighted, comfortable way. A colleague works hard, takes on many chores, and is pleasant and convenient to have around. But an impartial and incisive analysis of the member's tone of attack in creative work leaves much to be desired. While some men go through cycles of more and less productive periods in their scholarly work, it is safe to say that in the case of younger colleagues, at least, any doubts in respect to creative potential are likely to increase as years pass. Routine duties may become a compensating self-justification for lack of enthusiasm or energy for creative effort. It is no kindness to hold a man in an environment of deepening frustration when he might gain continuing satisfaction as a useful college teacher rather than as a creative teacher-scholar in a demanding university. Again, it is the obligation of the central administration to question the kindly, comfortable attitudes of peer groups and, if necessary, to seek outside evaluations not clouded by sentiment.

There is probably no aspect of faculty administration which is more certain to arouse public criticism than the attitude expressed in the slogan "publish or perish." The misunderstanding of the very important role of publication in the evaluation of creative men lies in the shift from ends to means. To the public, and to the eventual user of knowledge, whether in academia or industry, the published book or article stands as a contribution in itself. To the peer group within the university and to the central administration, the publication is a means of gaining insight into the creative powers, the tone of attack, the self-discipline, and general motivation of the author. Books and articles are only one means of "entering" a man's mind, but they have the important attribute that, through widespread distribution, they can be read critically by large numbers of people not influenced by personal association with the author. Also, in the words of Bacon, "writing maketh the exact man." Errors or sloppiness which can be covered up in oral discussion become apparent in the written statement. It is not the amount of writing, but the quality and insight shown in writing which are the true measure of publication. The pace of publication of a creative teacher-scholar is affected by many factors, but a prolonged absence of flow from the spring suggests doubts concerning the vitality of the source.

Not all disciplines lend themselves to major dependence upon

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publication as the test of men's minds. In some areas, such as public affairs, many contributions to knowledge and understanding are joint products in which individual authorship is submerged. Also, some scholars find their greatest satisfaction in stimulating colleagues and students and in contributing the germs of ideas for others to nourish and perfect. Criticism itself can be creative in the larger sense. Occasionally a truly creative scholar transmits most of his hard-won wisdom through consultation both within and outside the academic group. The best approach in dealing with men of diverse talents and inclinations is to seek to judge their creativity on an individual basis by the outward manifestations which occur through time. It must be admitted, however, that a creative teacher-scholar who writes little must stand the test of close scrutiny of all the other means of communication which he may find preferable.

There is no more ambiguous expression in academia than that a professor is a "good teacher." In the mouth of a freshman concerned with staying in college, a good teacher may be one who so organizes and simplifies a body of material that any mediocre student who stays awake and reviews his notes can pass the course. Or the good teacher may be the enthusiastic lecturer who, by interesting illustration, makes a subject exciting. But the true test of a good teacher is what he does to the student in the drawing forth—the education—of the student's powers of clear thinking, analysis, orderly accumulation, evaluation, and re-creation of ideas in his own terms. The good teacher changes men rather than transmits knowledge for its own sake. In the earlier stages of college or university education, there is need for good "coaches" in the learning process, in the development of tools such as language, mathematics, laboratory techniques, and the use of libraries. But in the later years of education, and especially in graduate work, there is need for teacher-scholars who, through their own zeal for thinking things anew, transmit the excitement of the process to their students. With such teachers, the man is more important than the method.

In the evaluation of the qualities of a creative teacher-scholar as a *teacher*, it is necessary to keep clearly in mind the role in which he can contribute most. There are teachers of enthusiasm and effectiveness who make the art of teaching at a more elementary level a life-long subject of study. A number of such scholars of teaching are a valuable supporting cast in any university. Their facility in attracting student interest in what is already known should not be permitted to upstage the teacher-scholar who in his

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drive toward discovery of new approaches and ideas in his discipline may at times leave his students breathless and confused. The ideal, of course, is the perfect blend of the dynamic scholar and the ever-lucid, ever-patient teacher; but in the absence of any large reservoir of such persons, most universities must be satisfied with the compensating attributes of a balanced team. It is the task of the university, however, to establish the assumption that the precious norm is the balanced teacher-scholar, and that one-sidedness is a shortcoming rather than a source of distinction.

Given the nature of the creative teacher-scholar and assuming some success in recruiting and evaluating individuals who appear to possess these attributes, it might be presumed that sound scholarship and effective teaching will automatically ensue. A university is more dependent upon the initiative of its members than almost any other form of organization, but it is still an organized community, sensitive to leadership, tradition, common and statute law, equity, and mutual support. The creative individual is peculiarly responsive to these aspects of his environment.

Leadership and tradition—which is the projection of leadership through time—can greatly influence the environment in which scholarship takes place. Such leadership encompasses both the administration and the senior faculty. Its manifestations include assumptions of dedication, integrity, freedom, persistence in seeking fundamental truth rather than quick and useful answers, cooperation rather than self-centered interest, and the dignity of every individual. Farsighted planning for the support of the individual scholar in library and laboratory resources, strong colleagues, good students, and effective staff are the obvious requirements which an administration must fulfill. Good departmental organization which produces results with a minimum of wasted time or friction is the product of leadership at the most immediate level.

As was suggested earlier in this essay, the truly creative scholar must possess the capacity to move through a cycle of analysis and accumulation, followed by intuitive thought and again by a period of testing and retesting of the new concepts gained. Not only is the *capacity* required, but also the time and specialized resources to use this capacity. The modern university has learned this slowly. It has also learned that scholars in different disciplines need very different patterns of time and resources. The scholar in the humanities needs blocks of time and a richly endowed library, wherever it may be. The older concept of the sabbatical year is too rigid in timing and

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often too long delayed. A whole battery of measures for leave or partial relief of teaching must be provided on an equitable basis which takes individual needs into consideration. Younger scholars need assurance of relief from teaching even though projects and potential are still uncertain. It is difficult to test creative potential if no time is afforded to demonstrate it. Opportunity for intensive periods of analysis and accumulation is of great help, but even more important is uninterrupted time for the intuitive kind of thinking. Most of all, perhaps, the humanistic scholar benefits from free time during the period when consolidation, testing, and writing must be done.

The social scientist in the university has turned more and more a staff-supported research and the scientist to team research with graduate students. Time, facilities, and staff must be provided. It is fortunate that the government and the foundations are now providing much support for research in these fields. But, again, a mistake is made if the day-to-day pressures of "organized" research crowd out time for intuitive thought and recharging of intellectual batteries in the creative individual. For their own survival as centers of free-ranging creative effort, the liberal universities of the country must make sure that scholarship and research by their faculties are not limited by the predispositions of government panels or foundation staffs, no matter how wise these may be. Creative scholarship can be hemmed in by undue respect for logic, whether in the individual or in the institutional setting in which he must work.

It has been suggested earlier in this analysis that creative teacher-scholars are likely to be introspective perfectionists, not disposed to respect the judgments of those outside their fields. While exceptions occur, the by-product of this attitude is often a lack of interest in the details of personal budgeting, retirement annuities, insurance, mortgages, and savings and, at the same time, a tendency to worry more than most about the risks of modern life. It is the responsibility of the university to provide a supporting framework. This is not only a reflection of the evolution of good industrial relations in progressive corporations, but a peculiarly important function in an institution whose chief asset is a body of creative men.

The wise university administration today does not leave the decision to participate in retirement programs, group life insurance, or major medical expense insurance to the individual faculty member. This is not an act of paternalism, but rather a mutually ac-

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cepted bargain. The university is a perpetual institution which can average risks over time. It offers a lifetime of employment to its tenure faculty. It has learned that its faculty is more productive over the years if it is relieved of certain details of the business of living for which the university can provide expert insurance service. Whereas a storekeeper or a corporation executive may enjoy competitive taking of risks and planning to minimize loss, the creative teacher-scholar faces competition and risk in the world of ideas and in the varying reaction of students and colleagues. Uncertain of continuing success, even with sustained effort, he prefers to limit his economic risks through the help of his university.

The pattern of university salaries through a period of career service seldom matches the varying needs of the faculty member. The creative teacher-scholar usually attains his highest salary very late in life. His needs for the housing of his family and the education of his children come to a peak long before his salary does. Liberal arrangements for rental housing, for mortgage loans, and for children's college tuition are means of readjusting the pattern of compensation to the pattern of need. Such programs may seem to be little related to a climate for creative thinking until one deals with a distraught physicist who has been house-hunting for weeks or a linguist with three college-age children. The notion that creativity is sharpened by financial insecurity should be reserved for romantic stories of bygone days.

Probably the most precious source of personal security for the creative teacher-scholar is the assurance that he will receive fair and equitable treatment by his peers and his university. This does not mean that he will always get what he wants, but that he gets, over time, what he truly deserves in comparison with others. The need for sound and positive personnel administration is more critical in universities than anywhere else because of the nature of creative men. At the same time, it is a difficult and complex form of personnel administration because of the diverse and intangible qualities to be encouraged, measured, and rewarded. It is a proper field of study for all concerned in the advancement of higher education. Impersonal, bureaucratic methods which create and rigidify inequities in individual or categorical salaries or status in a university can cause more loss in morale than heavy teaching loads. To assure a creative faculty, a university should indulge in creative thinking about the way in which individuals are developed and

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rewarded for careers of creativity as well as for all other forms of contribution to the mission of higher education.

America has become accustomed to meeting its vastly increasing needs for goods and services by ingenious extensions of mass production and large-scale organization. There is now a sharply increased need for creative teacher-scholars to man our colleges and universities and to advance knowledge as a basis for growth and human welfare. It appears likely that this particular need will not be met easily or by any radical change in methods or organization. The reasons are that the nature of the creative teacher-scholar is such that highly individualized methods must be used to discover, recruit, and develop persons of such talent and that these methods become more difficult to sustain as organizations become larger. It behooves us, therefore, to study and perfect the arts of administration in the university of limited size as a time-tested source of high talent while experimenting with the more spectacular operations of the multi-versity. The resolution of the dichotomy of scale and quality remains an American challenge.

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CLIFF W. WING, JR.

Student Selection, the Educational Environment, and the Cultivation of Talent

We have, in American higher education, a complex, variable system for the selection of students and an equally complex and variable system for their instruction. While both are important for the cultivation of talent, there has, to date, been remarkably little effort made to relate the two. Information collected by admissions offices has recently been used to help place first-year students in courses appropriate to their ability and achievement; it has rarely served as a source of guidance for the faculty charged with curriculum design and instruction. Conversely, except for grades at the end of the freshman year and records of drop-outs and failures, the results of exposing students to various educational practices are seldom even considered, much less related to the original selection process.

Current Status of Selection. Pressed toward objectivity by the force of large numbers of college applicants, admissions offices have developed actuarial tables relating the credentials of applicants to some of their college performance. A decade or more of experience has made possible fairly accurate prediction of freshman average grades, for example. Techniques in popular use for the selection of college students—systematic analyses of high school records, test scores, and recommendations—have been of major importance in effecting positive changes in our educational institutions. Selection has helped raise the quality of graduating classes by identifying students who possess the general ability to succeed in given colleges; it has decreased the rate of academic attrition by discouraging admission of those who would probably fail; and, very importantly, it has given impetus to improvements in the academic curricula of secondary schools. The systematic utilization of objective data has, in short, helped to improve the average product of educational institutions at all levels. But, despite these contributions and accom-

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plishments, the admissions process in American higher education remains gross, unrefined, and unsophisticated, and provides little assistance in identifying genuinely creative talent.

What is wrong with the tools currently being used for the prediction of success in college? Why do they fail to detect creativity? Norman Mackworth recently supported the view that part of the fault may lie with the composition of selection tests. They seem to favor the problem-solvers over the problem-finders, the verbal reasoners over the intuitive thinkers, though the latter are the more truly creative.

It seems clear that a second reason that creativity is not being identified is that secondary-school records and test scores do not effectively differentiate among various specific talents. There are, observation tells us, different kinds of creativity—for writing poetry, painting pictures, solving abstract mathematical problems, designing physics experiments, providing political leadership. Talent of one kind often is correlated with talent of another: Two or more may exist side by side within the same individual. It is well known, for example, that people who score high on verbal tests tend also to score high on tests of mathematical ability. The reverse, however, may also occur: an individual may have, by reason of congenital ability, specific training, or direction of motivation, a peak of talent surrounded by valleys of less or almost no talent. He may, for example, have great scientific potential, yet find it difficult to mobilize his resources to study a foreign language.

Techniques currently being used for the prediction of success in college are restricted principally to an overall view of the high-school performance—the gross measure of average grades, rank in class—so that a sterling contribution to a chemistry class is not reflected in the class rank of a pupil who happens to be inept in French. Thus, an individual with a peak-and-valley distribution of creative ability is unlikely to be pinpointed by current selection methods. Tests and grading techniques therefore need to be developed for recognizing single great talents as well as abilities that are evenly distributed and highly intercorrelated.

There are two other reasons that current selection devices often overlook the highly talented. They fail to take into account the fact that creativity develops according to individual patterns, emerging earlier for some than for others, and evolving thereafter at different rates. It is probable that talent, despite variations, typically grows at a much faster rate during the first ten years of life than during

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the second ten. It follows that the difficulty of developing creativity to its full potential increases with the age of the individual at the time his ability is identified. Means for identifying creativity at an early age need to be developed and utilized in the selection process.

Still another area for improvement in selection lies in increased recognition of the fact that creativity knows no social, ethnic, religious, or geographical boundaries. It can appear at any time, any place, sometimes over apparently insurmountable odds. Yet, secondary-school records and test scores, the main bases for admissions policies, tend to favor those applicants who have had an opportunity to acquire prescribed skills. A child with important latent ability may therefore be evaluated as inferior. New techniques for identifying potential creativity must be developed so that they will not discriminate, or will discriminate less, against a child from disadvantaged circumstances. There are indications that some national testing organizations are beginning to make efforts along these lines and to take cognizance of suggestive research being performed in university settings. In the meantime, it is noteworthy that increasing numbers of admissions officers now tend to evaluate the records of disadvantaged students rather differently from those of students from culturally more affluent homes, and to admit some of the former who previously would have been rejected. On the basis of these admissions, data are just beginning to be developed which might ultimately be used to help make more accurate adjustments in interpreting records for students from disadvantaged backgrounds.

If cultural biases exist, we must be aware of them and their influence so that proper compensations can be made in the selection process and so that proper educational programs can be designed to help improve the training of talent available in each subculture. In other words, we need to know about the interaction of the individual with his cultural setting in the cultivation of educational skills, abilities, and potential, as well as how the cultural setting during the early years is mediated by the individual and interacts with the stimulation of higher education.

Current Status of the Higher Education Environment. Unlike the admissions offices, which have been pressed by large numbers of applicants toward objective evaluation of the selection process, college faculties and administrative officials responsible for curriculum design and teaching have often changed courses and instruction without submitting the outcome of the changes to objective

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tests of effectiveness. Ideas like the "general education" curricular approach have often been introduced without developing factual information about the consequences to students. The introduction of unevaluated changes into the educational environment frequently has led us to return, like the swinging pendulum, to a position vacated only a few years before, with no record of the pendulum's course. As a result, we know very little about how to manipulate the various elements in the higher education environment to maximize the development of students' abilities.

Knowledge about the effect of the educational environment upon student development is of central and urgent importance to selection generally and to the selection and cultivation of creative talent specifically. Technically, the actuarial tables used for selection purposes are based upon college faculty assessment of students, and these assessments are formulated on the basis of student performance under the influence of a variety of curricular and instructional techniques: (1) Standard tests of aptitude, used nationally for selection, are composed of questions included because they discriminate accurately between students who will be judged successful by their college teachers, and students who will not. (2) The use of secondary-school records in selection also is highly dependent on college faculty assessments: an index shows, for instance, that a pupil who makes a B average at City High usually will maintain a B average at City College, whereas a pupil who maintains a B average at Town High will earn only a C average at City College. Admissions offices use information such as this in evaluating high-school records. Both standard aptitude tests and school grades, then, are utilized for selection purposes not in the absolute, but on the basis of their correlation with records of college assessments. It may be concluded that selection for college and effects of college environment are related in a circular fashion, and that one cannot properly be considered without the other.

The interdependence of selection and collegiate educational practices concerns us here especially in connection with the cultivation of creative ability—a process presumably involving both the selection of those with creative potential, and their educational nurture thereafter. The fact is that the current educational system fails, in general, to grant recognition to creativity. As matters now stand, we are probably losing potentially creative individuals at the college level in two ways: (1) We lose some indirectly by failing to select them for college, because selection tools are evaluated ac-

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cording to capacity to predict college performance and cannot be satisfactorily developed for detecting creativity without recognition of creativity at the college level. (2) We lose other students directly, because we fail to encourage them or fail to recognize their specific talents in college.

Current collegiate educational practices seem designed to do the opposite of what we should want them to do: They grant premium recognition not to creativity but to average performance. Note the many ways employed formally by our higher educational system to encourage well-roundedness and discourage specialization in a single area: For example, progress through college, graduation, and even admission to graduate school are often based on performance in all fields, not just one. A student with a C average, making all C's, gets through; a C-average student with an A in physics and an F in English does not. Official sanction is given to average achievement and withheld from peak accomplishment in one field surrounded by valleys of indifferent or poor performance in others. The present grading system also discourages single-field creativity. Using only one grade, only one kind of grade, may completely obscure the difference between the student who achieves an A by dogged persistence, good study habits, and uninspired but correct answers and another who earns his A through brilliant insights and original solutions.

Probably the most profound deterrent to the recognition and development of creativity is inflexibility in the college curriculum. There are two kinds of inflexibility. First, a sampling of courses from the sciences, social studies, humanities and arts usually is required during the first two college years, specialization allowed only later. Assuming that a liberal education is a desirable goal for everybody, including those who are enormously creative in some one field (and there are many who would challenge that assumption!), what is sacred about the first two years of college as the time for promulgating it? Yet curricular requirements around the country are almost uniformly inflexible in this regard. Second, the sequence of courses designed internally by the various departments on the college campus inhibits flexibility. Progression may be based on some agreed-upon logical ordering of the discipline itself. But what of the developmental patterns of the individual student who is concentrating in the field? Suppose he comes to a discipline highly excited about one small portion of it, and suppose he shows creativity, or unusual ability. Under present conditions, he is not allowed to

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probe the area of his interest but is told to wait for two years, learn the broader subject matter first, and later perhaps relate it to the current focal point. In short, inflexibility in ordering courses within a given discipline may force a creative person to grow wide before he grows tall—even though growth forced in this way may stifle talent.

Two additional points about current educational procedures and their effect upon the cultivation of talent bear mention. First, educational institutions insist upon being exceedingly vague about their purposes. Nearly all liberal arts colleges or university divisions, many junior colleges, and some institutes and technical schools state their goals so broadly that one institution is indistinguishable from the others. Over-generalized statements provide little basis for making sophisticated selections of one type of college environment in preference to another. Such statements prevent students from learning pertinent specific information—for example, that course offerings at a certain college are particularly good in chemistry and biology and in English and history. At the present time, colleges avoid specifying their departmental strengths because to do so would imply relative weakness in the departments not named. Yet it is likely that no college offers a uniformly strong faculty in all departments, does everything equally well, or remains static in its outstanding contributions.

Second, we must not lose sight of the fact that students brought together on the same campus learn from each other. Because this interaction and mutual stimulation are a significant part of each student's educational environment, it is important to have different kinds of talent on the same campus—individuals with special gifts for chemistry, poetry, and other fields of study. Currently, efforts to compose classes representing different backgrounds concentrate more upon wide geographic, social, and cultural distribution than upon representation of a variety of specific intellectual talents.

A Proposed Model for Selection. The foregoing discussion indicates that there is a chicken-or-the-egg interdependency between selection problems and educational problems related to the cultivation of talent. Techniques for identifying unusual ability need to be developed. At the same time, they need to be evaluated against tangible, explicit signs of recognition of talent within the educational system. Coupled with the needs for modification to help achieve more nearly ideal conditions are certain practical matters that also must be considered.

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